NUTRITION

SCIENCE AND APPLICATIONS

Lori Smolin | Mary Grosvenor

4th EDITION

Wiley Binder Version

WILEY

Dietary Reference Intakes: Recommended Intakes for Individuals: Vitamins

Life Stage Group	Vitamin A (μg/day)[a]	Vitamin C (mg/day)	Vitamin D (μg/day)[b,c]	Vitamin E (mg/day)[d]	Vitamin K (μg/day)	Thiamin (mg/day)	Riboflavin (mg/day)	Niacin (mg/day)[e]	Vitamin B_6 (mg/day)	Folate (μg/day)[f]	Vitamin B_{12} (μg/day)	Pantothenic Acid (mg/day)	Biotin (μg/day)	Choline (mg/day)[g]
Infants														
0–6 mo	400*	40*	10*	4*	2.0*	0.2*	0.3*	2*	0.1*	65*	0.4*	1.7*	5*	125*
6–12 mo	500*	50*	10*	5*	2.5*	0.3*	0.4*	4*	0.3*	80*	0.5*	1.8*	6*	150*
Children														
1–3 y	**300**	**15**	**15**	**6**	30*	**0.5**	**0.5**	**6**	**0.5**	**150**	**0.9**	2*	8*	200*
4–8 y	**400**	**25**	**15**	**7**	55*	**0.6**	**0.6**	**8**	**0.6**	**200**	**1.2**	3*	12*	250*
Males														
9–13 y	**600**	**45**	**15**	**11**	60*	**0.9**	**0.9**	**12**	**1.0**	**300**	**1.8**	4*	20*	375*
14–18 y	**900**	**75**	**15**	**15**	75*	**1.2**	**1.3**	**16**	**1.3**	**400**	**2.4**	5*	25*	550*
19–30 y	**900**	**90**	**15**	**15**	120*	**1.2**	**1.3**	**16**	**1.3**	**400**	**2.4**	5*	30*	550*
31–50 y	**900**	**90**	**15**	**15**	120*	**1.2**	**1.3**	**16**	**1.3**	**400**	**2.4**	5*	30*	550*
51–70 y	**900**	**90**	**15**	**15**	120*	**1.2**	**1.3**	**16**	**1.7**	**400**	**2.4**[h]	5*	30*	550*
>70 y	**900**	**90**	**20**	**15**	120*	**1.2**	**1.3**	**16**	**1.7**	**400**	**2.4**[h]	5*	30*	550*
Females														
9–13 y	**600**	**45**	**15**	**11**	60*	**0.9**	**0.9**	**12**	**1.0**	**300**	**1.8**	4*	20*	375*
14–18 y	**700**	**65**	**15**	**15**	75*	**1.0**	**1.0**	**14**	**1.2**	**400**[i]	**2.4**	5*	25*	400*
19–30 y	**700**	**75**	**15**	**15**	90*	**1.1**	**1.1**	**14**	**1.3**	**400**[i]	**2.4**	5*	30*	425*
31–50 y	**700**	**75**	**15**	**15**	90*	**1.1**	**1.1**	**14**	**1.3**	**400**[i]	**2.4**	5*	30*	425*
51–70 y	**700**	**75**	**15**	**15**	90*	**1.1**	**1.1**	**14**	**1.5**	**400**	**2.4**[h]	5*	30*	425*
>70 y	**700**	**75**	**20**	**15**	90*	**1.1**	**1.1**	**14**	**1.5**	**400**	**2.4**[h]	5*	30*	425*
Pregnancy														
14–18 y	**750**	**80**	**15**	**15**	75*	**1.4**	**1.4**	**18**	**1.9**	**600**[j]	**2.6**	6*	30*	450*
19–30 y	**770**	**85**	**15**	**15**	90*	**1.4**	**1.4**	**18**	**1.9**	**600**[j]	**2.6**	6*	30*	450*
31–50 y	**770**	**85**	**15**	**15**	90*	**1.4**	**1.4**	**18**	**1.9**	**600**[j]	**2.6**	6*	30*	450*
Lactation														
14–18 y	**1200**	**115**	**15**	**19**	75*	**1.4**	**1.6**	**17**	**2.0**	**500**	**2.8**	7*	35*	550*
19–30 y	**1300**	**120**	**15**	**19**	90*	**1.4**	**1.6**	**17**	**2.0**	**500**	**2.8**	7*	35*	550*
31–50 y	**1300**	**120**	**15**	**19**	90*	**1.4**	**1.6**	**17**	**2.0**	**500**	**2.8**	7*	35*	550*

Note: This table (taken from the DRI reports, see www.nap.edu) presents Recommended Dietary Allowances (RDAs) in **bold** type and Adequate Intakes (AIs) in ordinary type followed by an asterisk (*). RDAs and AIs may both be used as goals for individual intakes. RDAs are set to meet the needs of almost all (97 to 98 percent) healthy individuals in a group. For healthy breastfed infants, the AI is the mean intake. The AI for all other life stage and gender groups is believed to cover the needs of all healthy individuals in the groups, but lack of data or uncertainty in the data prevent being able to specify with confidence the percentage of individuals covered by this intake.

[a]As retinol activity equivalents (RAEs). 1 RAE = 1 μg retinol, 12 μg β-carotene, 24 μg α-carotene, or 24 μg β-cryptoxanthin. The RAE for dietary provitamin A carotenoids is two-fold greater than retinol equivalents (REs), whereas the RAE for preformed vitamin A is the same as the RE.

[b]As cholecalciferol. 1 μg cholecalciferol = 40 IU vitamin D.

[c]Under the assumption of minimal sunlight.

[d]As α-tocopherol, which includes RRR-α-tocopherol, the only form of α-tocopherol that occurs naturally in foods, and the 2R-stereoisomeric forms of α-tocopherol (RRR-, RSR-, RRS, and RSS-α-tocopherol) that occur in fortified foods and supplements. It does not include the 2S-stereoisomeric forms of α-tocopherol (SRR-, SSR-, SRS-, and SSS-α-tocopherol), also found in fortified foods and supplements.

[e]As niacin equivalents (NEs), 1 mg niacin = 60 mg tryptophan; 0–6 months = preformed niacin (not NE).

[f]As dietary folate equivalents (DFE). 1 DFE = 1 μg food folate = 0.6 μg folic acid from fortified food or as a supplement consumed with food = 0.5 μg of a supplement taken on an empty stomach.

[g]Although AIs have been set for choline, there are few data to assess whether a dietary supply of choline is needed at all stages of the lifecycle, and it may be that the choline requirement can be met by endogenous synthesis at some of these stages.

[h]Because 10–30% of older people may malabsorb food-bound B_{12} it is advisable for those older than 50 years to meet their RDA mainly by consuming foods fortified with B_{12} or a supplement containing B_{12}.

[i]In view of evidence linking folate intake with neural tube defects in the fetus, it is recommended that all women capable of becoming pregnant consume 400 μg from supplements or fortified foods in addition to intake of food folate from a varied diet.

[j]It is assumed that women will consume 400 μg from supplements or fortified foods until their pregnancy is confirmed and they enter prenatal care, which ordinarily occurs after the end of the periconceptional period—the critical time for neural tube formation.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences available online at www.nap.edu. Reprinted with permission from *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements* , 2006, by the National Academy of Sciences, Washington, D.C. Institute of Medicine, Food and Nutrition Board Dietary Reference Intakes for Calcium and Vitamin D (2011), National Academies Press, Washington DC, 2011.

Dietary Reference Intakes: Recommended Intakes for Individuals: Minerals

Life Stage Group	*Calcium (mg/day)*	*Chromium (µg/day)*	*Copper (µg/day)*	*Fluoride (mg/day)*	*Iodine (µg/day)*	*Iron (mg/day)*	*Magnesium (mg/day)*	*Manganese (mg/day)*	*Molybdenum (µg/day)*	*Phosphorous (mg/day)*	*Selenium (µg/day)*	*Zinc (mg/day)*	*Sodium (g/day)*	*Chloride (g/day)*	*Potassium (g/day)*
Infants															
0–6 mo	200*	0.2*	200*	0.01*	110*	0.27*	30*	0.003*	2*	100*	15*	2*	0.12*	0.18*	0.4*
6–12 mo	260*	5.5*	220*	0.5*	130*	**11**	75*	0.6*	3*	275*	20*	**3**	0.37*	0.57*	0.7*
Children															
1–3 y	**700**	11*	**340**	0.7*	**90**	**7**	**80**	1.2*	**17**	**460**	**20**	**3**	1.0*	1.5*	3.0*
4–8 y	**1000**	15*	**440**	1*	**90**	**10**	**130**	1.5*	**22**	**500**	**30**	**5**	1.2*	1.9*	3.8*
Males															
9–13 y	**1,300**	25*	**700**	2*	**120**	**8**	**240**	1.9*	**34**	**1,250**	**40**	**8**	1.5*	2.3*	4.5*
14–18 y	**1,300**	35*	**890**	3*	**150**	**11**	**410**	2.2*	**43**	**1,250**	**55**	**11**	1.5*	2.3*	4.7*
19–30 y	**1,000**	35*	**900**	4*	**150**	**8†**	**400**	2.3*	**45**	**700**	**55**	**11**	1.5*	2.3*	4.7*
31–50 y	**1,000**	35*	**900**	4*	**150**	**8†**	**420**	2.3*	**45**	**700**	**55**	**11**	1.5*	2.3*	4.7*
51–70 y	**1,000**	30*	**900**	4*	**150**	**8†**	**420**	2.3*	**45**	**700**	**55**	**11**	1.3*	2.0*	4.7*
> 70 y	**1,200**	30*	**900**	4*	**150**	**8†**	**420**	2.3*	**45**	**700**	**55**	**11**	1.2*	1.8*	4.7*
Females															
9–13 y	**1,300**	21*	**700**	2*	**120**	**8**	**240**	1.6*	**34**	**1,250**	**40**	**8**	1.5*	2.3*	4.5*
14–18 y	**1,300**	24*	**890**	3*	**150**	**15†‡**	**360**	1.6*	**43**	**1,250**	**55**	**9**	1.5*	2.3*	4.7*
19–30 y	**1,000**	25*	**900**	3*	**150**	**18†‡**	**310**	1.8*	**45**	**700**	**55**	**8**	1.5*	2.3*	4.7*
31–50 y	**1,000**	25*	**900**	3*	**150**	**18†‡**	**320**	1.8*	**45**	**700**	**55**	**8**	1.5*	2.3*	4.7*
51–70 y	**1,200**	20*	**900**	3*	**150**	**8†**	**320**	1.8*	**45**	**700**	**55**	**8**	1.3*	2.0*	4.7*
> 70 y	**1,200**	20*	**900**	3*	**150**	**8†**	**320**	1.8*	**45**	**700**	**55**	**8**	1.2*	1.8*	4.7*
Pregnancy															
14–18 y	**1,300**	29*	**1,000**	3*	**220**	**27**	**400**	2.0*	**50**	**1,250**	**60**	**12**	1.5*	2.3*	4.7*
19–30 y	**1,000**	30*	**1,000**	3*	**220**	**27**	**350**	2.0*	**50**	**700**	**60**	**11**	1.5*	2.3*	4.7*
31–50 y	**1,000**	30*	**1,000**	3*	**220**	**27**	**360**	2.0*	**50**	**700**	**60**	**11**	1.5*	2.3*	4.7*
Lactation															
14–18 y	**1,300**	44*	**1,300**	3*	**290**	**10**	**360**	2.6*	**50**	**1,250**	**70**	**13**	1.5*	2.3*	5.1*
19–30 y	**1,000**	45*	**1,300**	3*	**290**	**9**	**310**	2.6*	**50**	**700**	**70**	**12**	1.5*	2.3*	5.1*
31–50 y	**1,000**	45*	**1,300**	3*	**290**	**9**	**320**	2.6*	**50**	**700**	**70**	**12**	1.5*	2.3*	5.1*

Note: This table (taken from the DRI reports, see www.nap.edu) presents Recommended Dietary Allowances (RDAs) in **bold** type and Adequate Intakes (AIs) in ordinary type followed by an asterisk (*). RDAs and AIs may both be used as goals for individual intakes. RDAs are set up to meet the needs of almost all (97–98%) healthy individuals in a group. It is calculated from an EAR. If sufficient scientific evidence is not available to establish an EAR, and thus calculate an RDA, an AI is usually developed. For healthy breastfed infants, the AI is the mean intake. The AI for all other life stage and gender groups is believed to cover the needs of all healthy individuals in the groups, but lack of data or uncertainty in the data prevent being able to specify with confidence the percentage of individuals covered by this intake.

† The RDA is increased for vegetarians. Value = RDA × 1.8

‡ The RDA is increased for women taking oral contraceptives for 14–18 years = 11.4 mg/day, for 19–50 years = 10.9 mg/day.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences. Available online at www.nap.edu. Reprinted with permission from *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements,* 2006, by the National Academy of Sciences, Washington, D.C. Institute of Medicine, Food and Nutrition Board Dietary Reference Intakes for Calcium and Vitamin D (2011), National Academies Press, Washington DC, 2011.

Acceptable Macronutrient Distribution Ranges (AMDR) for Healthy Diets as a Percent of Energy

Age	*Carbohydrate*	*Added Sugars*	*Total Fat*	*Linoleic Acid*	*α-Linolenic Acid*	*Protein*
1–3 y	45–65	≤25	30–40	5–10	0.6–1.2	5–20
4–18 y	45–65	≤25	25–35	5–10	0.6–1.2	10–30
≥19 y	45–65	≤25	20–35	5–10	0.6–1.2	10–35

Source: Institute of Medicine, Food and Nutrition Board. "Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids." Washington, D.C.: National Academies Press, 2002, 2005.

Dietary Reference Intakes: Recommended Intakes for Individuals: Carbohydrates, Fiber, Fat, Fatty Acids, Protein, and Water

Life Stage Group	*Carbohydrate (g/day)*	*Fiber (g/day)*	*Fat (g/day)*	*Linoleic Acid (g/day)*	*α-Linolenic Acid (g/day)*	*Protein*		*Water*[b] *(L/day)*
						(g/kg/day)[a]	*(g/day)*	
Infants								
0–6 mo	60*	ND	31*	4.4*†	0.5*‡	1.52*	9.1*	0.7*
6–12 mo	95*	ND	30*	4.6*†	0.5*‡	1.50	11.0	0.8*
Children								
1–3 y	130	19*	ND	7*	0.7*	1.10	13	1.3*
4–8 y	130	25*	ND	10*	0.9*	0.95	19	1.7*
Males								
9–13 y	130	31*	ND	12*	1.2*	0.95	34	2.4*
14–18 y	130	38*	ND	16*	1.6*	0.85	52	3.3*
19–30 y	130	38*	ND	17*	1.6*	0.80	56	3.7*
31–50 y	130	38*	ND	17*	1.6*	0.80	56	3.7*
51–70 y	130	30*	ND	14*	1.6*	0.80	56	3.7*
>70 y	130	30*	ND	14*	1.6*	0.80	56	3.7*
Females								
9–13 y	130	26*	ND	10*	1.0*	0.95	34	
14–18 y	130	26*	ND	11*	1.1*	0.85	46	2.1*
19–30 y	130	25*	ND	12*	1.1*	0.80	46	2.3*
31–50 y	130	25*	ND	12*	1.1*	0.80	46	2.7*
51–70 y	130	21*	ND	11*	1.1*	0.80	46	2.7*
>70 y	130	21*	ND	11*	1.1*	0.80	46	2.7*
Pregnancy	175	28*	ND	13*	1.4*	1.10	71	3.0*
Lactation	210	29*	ND	13*	1.3*	1.10	71	3.8*

ND = not determined. *Values are AI (Adequate Intakes), † Refers to all ω-6 polyunsaturated fatty acids, ‡ Refers to all ω-3 polyunsaturated fatty acids.

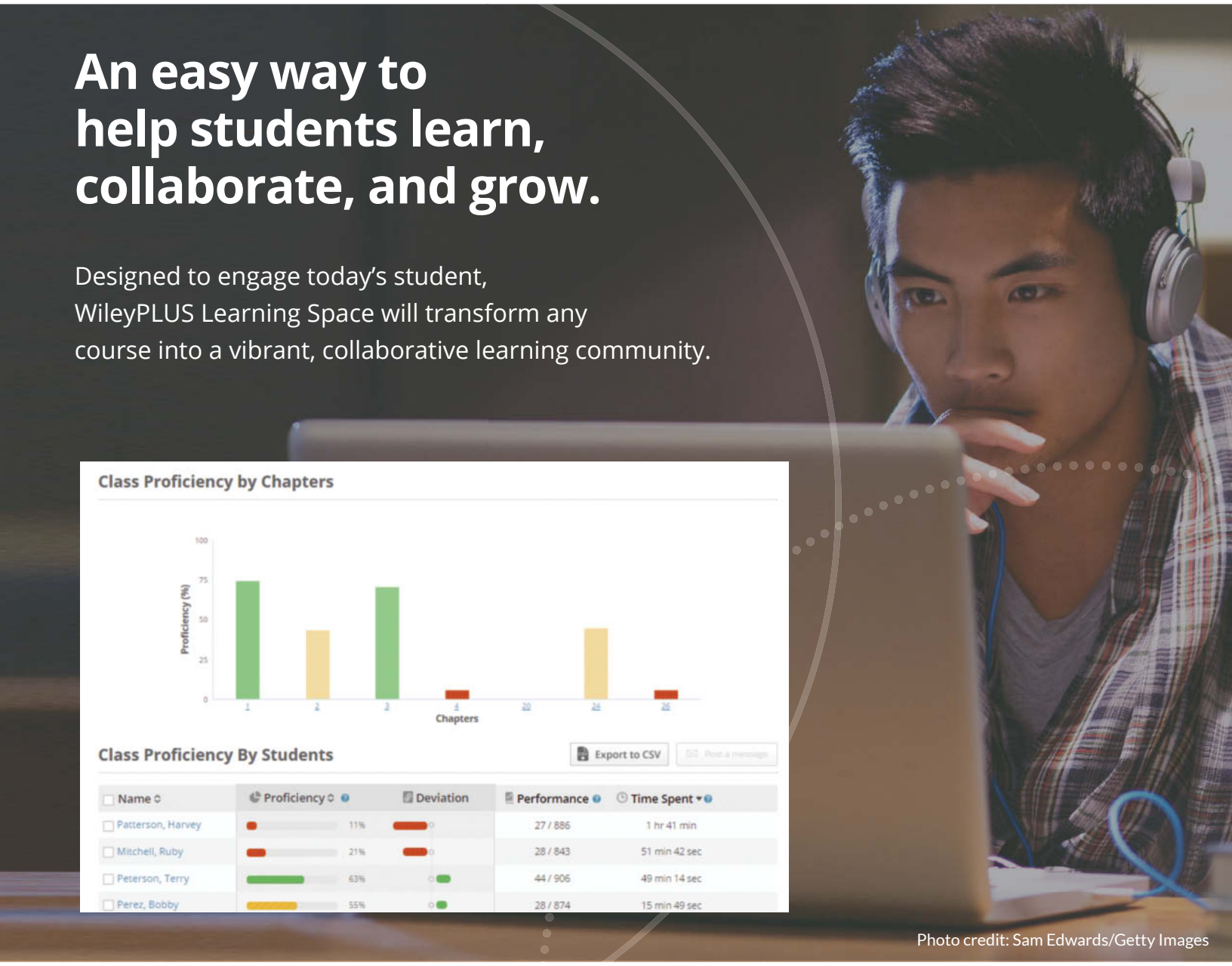
[a] Based on g protein per kg of body weight for the reference body weight, e.g., for adults 0.8 g/kg body weight for the reference body weight.

[b] Total water includes all water contained in food, beverages, and drinking water.

Source: Institute of Medicine, Food and Nutrition Board. "Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids" (2002/2005); "Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate" (2005). Washington, D.C.: National Academies Press.

WileyPLUS Learning Space

Includes **ORION** Adaptive Practice



An easy way to help students learn, collaborate, and grow.

Designed to engage today's student, WileyPLUS Learning Space will transform any course into a vibrant, collaborative learning community.

Photo credit: Sam Edwards/Getty Images

Identify which students are struggling early in the semester.

Educators assess the real-time engagement and performance of each student to inform teaching decisions. Students always know what they need to work on.

Facilitate student engagement both in and outside of class.

Educators can quickly organize learning activities, manage student collaboration, and customize their course.

Measure outcomes to promote continuous improvement.

With visual reports, it's easy for both students and educators to gauge problem areas and act on what's most important.

www.wileypluslearningspace.com

WILEY

NUTRITION

SCIENCE AND APPLICATIONS

4th EDITION

WILEY

NUTRITION

SCIENCE AND APPLICATIONS

Lori Smolin
University of Connecticut

Mary Grosvenor

4th EDITION

WILEY

VICE PRESIDENT & DIRECTOR	Petra Recter
DIRECTOR	Kevin Witt
EXECUTIVE EDITOR	Ryan Flahive
EXECUTIVE MARKETING MANAGER	Clay Stone
ASSOCIATE DEVELOPMENT EDITOR	Lauren Elfers
MARKET SOLUTIONS ASSISTANT	Emma Townsend-Merino / Mili Ali
DESIGN DIRECTOR	Harry Nolan
CONTENT MANAGER	Kevin Holm
SENIOR MEDIA SPECIALIST	Svetlana Barskaya
SENIOR PRODUCTION EDITOR	Patricia McFadden
SENIOR PHOTO EDITOR	Mary Ann Price
TEXT DESIGN	Wendy Lai
COVER DESIGN	Wendy Lai

Cover Photo: Ian Knaggs Photography/Getty Images
Chapter Outline Icons: iStockphoto

This book was set in Minion Pro Regular 10/12 pt by Aptara®, Inc. and printed and bound by Courier Companies.

This book is printed on acid-free paper.

Founded in 1807, John Wiley & Sons, Inc. has been a valued source of knowledge and understanding for more than 200 years, helping people around the world meet their needs and fulfill their aspirations. Our company is built on a foundation of principles that include responsibility to the communities we serve and where we live and work. In 2008, we launched a Corporate Citizenship Initiative, a global effort to address the environmental, social, economic, and ethical challenges we face in our business. Among the issues we are addressing are carbon impact, paper specifications and procurement, ethical conduct within our business and among our vendors, and community and charitable support. For more information, please visit our website: www.wiley.com/go/citizenship.

Copyright © 2016 John Wiley & Sons, Inc. All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923 (website: www.copyright.com). Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030-5774, (201) 748-6011, fax (201) 748-6008, or online at: www.wiley.com/go/permissions.

Evaluation copies are provided to qualified academics and professionals for review purposes only, for use in their courses during the next academic year. These copies are licensed and may not be sold or transferred to a third party. Upon completion of the review period, please return the evaluation copy to Wiley. Return instructions and a free-of-charge return shipping label are available at: www.wiley.com/go/returnlabel. If you have chosen to adopt this textbook for use in your course, please accept this book as your complimentary desk copy. Outside of the United States, please contact your local sales representative.

Library of Congress Cataloging in Publication Data:

ISBN (BRV): 978-1-119-08710-6
ISBN (EVALC): 978-1-119-23936-9

The inside back cover will contain printing identification and country of origin if omitted from this page. In addition, if the ISBN on the back cover differs from the ISBN on this page, the one on the back cover is correct.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

About the Authors

Lori A. Smolin received a bachelor of science degree from Cornell University, where she studied human nutrition and food science. She received a doctorate from the University of Wisconsin at Madison, where her doctoral research focused on B vitamins, homocysteine accumulation, and genetic defects in homocysteine metabolism. She completed postdoctoral training both at the Harbor–UCLA Medical Center, where she studied human obesity, and at the University of California–San Diego, where she studied genetic defects in amino acid metabolism. She has published articles in these areas in peer-reviewed journals. Dr. Smolin is currently at the University of Connecticut, where she has taught both in the Department of Nutritional Science and in the Department of Molecular and Cell Biology. Courses she has taught include introductory nutrition, life cycle nutrition, food preparation, nutritional biochemistry, general biochemistry, and introductory biology. In her spare time Dr. Smolin enjoys bicycling and watercolor painting.

Mary B. Grosvenor holds a bachelor of arts in English from Georgetown University and a master of science in Nutrition Science from the University of California at Davis. This combination provides her an ideal background for nutrition writing. She is a registered dietitian and has worked in clinical as well as research nutrition, in hospitals and communities, large and small, in the western United States. She teaches at the community college level and has published articles in peer-reviewed journals in nutritional assessment and nutrition and cancer. Her training and experience provide practical insights into the application and presentation of the science in this text.

Dedication

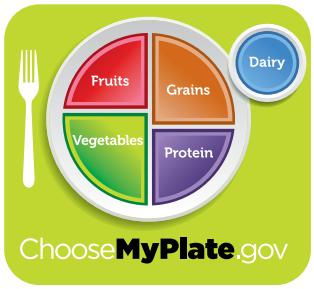
To my sons, Zachary and Max, and my husband David, for their love, support, and humorous outlook on life. To my mother, Shirlee Smolin, who is a testament to the health benefits of eating well and staying physically and mentally active.

LAS

To Peter, David, and John for their advice, patience, and editorial services, but most of all for continuing to remind me what is important in life.

MBG

Preface



Courtesy USDA

2011

Nutrition: Science and Applications, Fourth Edition, is intended as an introductory text for a science-oriented nutrition course. The material is appropriate for a college student at any level, freshman to senior, taking this course to fulfill a science requirement. The clear, concise writing style—reinforced visually with colorful, engaging illustrations and photographs—makes the science accessible. The strong metabolism coverage, clinical flavor, and critical-thinking approach to understanding science and nutrition research make this a text that will also prepare nutrition majors and other science majors for their future studies and careers. These students will discover that this text ties together information that they have studied in chemistry, physiology, biology, and biochemistry courses.

This up-to-date text includes the most recent recommendations from the DRIs, Dietary Guidelines, and MyPlate, as well as the food label changes proposed by the FDA. The text is extensively referenced from current literature. Recent concerns in nutrition science, such as nutritional genomics, the dual epidemics of obesity and diabetes, controlling world hunger, the risks and benefits of genetically modified foods, and the nutritional impact of dietary supplements, are discussed. The examples used throughout the text reflect the diverse ethnic and cultural mix of the American population.

Jeffrey Coolidge/Getty Images, Inc.

Critical Thinking Enhances Problem-Solving Skills

Nutrition: Science and Applications takes a critical-thinking approach to understanding and applying human nutrition. Like other introductory texts, it offers students the basics of nutrition by exploring the nutrients, their functions in the body, and sources in the diet. But its unique critical-thinking approach gives students an understanding of the "whys" and "hows" behind nutrition processes and explores the issues that surround nutrition controversies. Within each chapter, separate Critical Thinking exercises introduce nutrition-related problems. They then walk students through the process of first finding the facts, and then applying the logic needed to find solutions to the problems and to make healthy food and nutrition decisions. Application exercises, found online, ask students to use this same process of logical scientific inquiry, along with the information in the chapter, to analyze, modify and/or plan diets that promote health and reduce the risk of nutrient deficiencies and nutrition-related chronic diseases. "Think Critically" and "Analyze the Data" questions accompany many of the illustrations and photographs in the text and appear at the end of special features such as Debate, Off the Label, and Science Applied. These are designed to promote critical thought and focus student attention on the information in visuals or discussed in the features. This critical-thinking approach gives students the tools they need to bring nutrition out of the classroom and apply the logic of science to their own nutrition concerns—both as consumers and as future scientists and health professionals.

Charles D. Winters/Photo Researchers, Inc.

Integrated Metabolism Reinforces Understanding

Nutrition: Science and Applications is distinctive in its integrated approach to the presentation of nutrient metabolism. Metabolism is one of the most challenging topics for students, but a knowledge of metabolism is critical for understanding how nutrients function and impact human health. The text includes a comprehensive discussion of metabolism as it applies to each of the energy-yielding nutrients, shows how the micronutrients are involved, and then ties it all together in discussions of energy balance and fueling physical activity. The presentation differs from that in other texts, however, in integrating discussions of metabolism throughout appropriate chapters. This approach makes metabolism more manageable and

Jeffrey Coolidge/Getty Images, Inc.

memorable for students because it presents material in smaller segments and highlights its relevance to the nutrient being discussed. It also reinforces understanding of metabolic processes by revisiting key concepts with each nutrient and adding relevant new information. *Nutrition: Science and Applications* introduces a simple overview of metabolism in Chapter 3 and then builds on this base with more complex discussions in Chapters 4 through 10. For example, the discussion of carbohydrate metabolism in Chapter 4 presents the basics of glucose metabolism. This information is reviewed and augmented in chapters on lipids, proteins, micronutrients, energy balance, and exercise. Each discussion of metabolism is highlighted by the metabolism icon. To tie the concepts together, the illustrations use the same basic diagram with new information superimposed over familiar portions to demonstrate how each nutrient fits into the process. The nutrients and steps of metabolism are also color coded for easier recognition. Students or instructors who want to cover metabolism as a separate topic will find a slightly more in-depth summary online in Focus on Metabolism.

Integration of Health and Disease Relationships Holds Interest

© Mike Goldwater/Alamy Limited

Can I help my mom manage her blood cholesterol?

Why have I gained 10 pounds?

What should I eat to reduce my risk of cancer?

How can I change my diet to better support my athletic training?

These are some of the questions students want answered when they enroll in nutrition classes. To answer these and other health-related questions and to fuel student interest continuously, discussions of the relationships among nutrition, health, and disease are integrated throughout the text. The integration helps students recognize that a nutrient's function in the body is related to its role in health and disease. For example, just as discussing goiters in the section on iodine is logical and piques interest, so is discussing diabetes with carbohydrates, osteoporosis with calcium, and hypertension with sodium. Covering nutrition-related chronic conditions with the topic or nutrient most related to the issue continuously reinforces the applicability of nutrition science to the students' lives, and also helps them appreciate how and why their diet affects their health.

The Dietary Pattern, Not Individual Foods, Is the Focus

Nutrition: Science and Applications presents the message that each food choice makes up only a small part of your total diet and that it is the overall dietary pattern that determines the healthfulness of your diet. Each of the macronutrient chapters begins with a section that discusses the role of that nutrient in the diet—factors that affect our intake and how different food sources of each nutrient may make very different contributions to the diet. For example, a less-processed choice, such as whole-wheat bread, provides a more nutrient-dense source of carbohydrate than a slice of chocolate cake. However, this does not mean you can never have chocolate cake. The text emphasizes that there are no "bad" foods as long as the sum of food choices over a period of days or weeks makes up a healthy overall dietary pattern. To reinforce this, these chapters end with a discussion of how to meet your need for that specific nutrient while taking into consideration other dietary recommendations that promote health.

© Spaces Images/SuperStock

Distinctive Features

This text includes a number of features that both spark student interest and help them learn the basics of nutrition.

Chapter Outline

This brief outline of the chapter's content gives students and instructors an overview of the major topics presented in the chapter.

Case Study

Each chapter begins with a short case study. These health- and disease-oriented vignettes help spur student curiosity and provide a taste of some of the concepts to be explained in the chapter. For example, the case study for Chapter 6 describes the challenges a college student faces in choosing and meeting his nutrient needs with a vegan diet. The Chapter 10 case study recounts the story of an athlete who experienced dehydration during an Olympic marathon. The case study in Chapter 9 discusses a baby diagnosed with vitamin D deficiency. These intriguing and entertaining stories link the material in the chapter with everyday health and disease issues. The chapter content then helps students understand the issues associated with each case.

lucamanieri/iStockphoto

Proteins and Amino Acids

6

CHAPTER OUTLINE

6.1 **Protein in Our Food**
Sources of Protein in Our Diet
How Protein Sources Impact the Overall Diet

6.2 **Protein Molecules**
Amino Acid Structure
Protein Structure

6.3 **Protein in the Digestive Tract**
Protein Digestion
Amino Acid Absorption
Why Undigested Protein Can Cause Food Allergies

6.4 **Amino Acid Functions in the Body**
Proteins Are Continually Broken Down and Resynthesized
How Amino Acids Are Used to Synthesize Proteins
Synthesis of Nonprotein Molecules
How Amino Acids Provide Energy

6.5 **Functions of Body Proteins**
How Proteins Provide Structure
How Proteins Facilitate and Regulate Body Processes

6.6 **Protein, Amino Acids, and Health**
Protein Deficiency
Protein Excess
Protein and Amino Acid Intolerances

6.7 **Meeting Recommendations for Protein Intake**
How Protein Requirements Are Determined
Protein Recommendations
Translating Recommendations into Healthy Diets

6.8 **Vegetarian Diets**
What Are the Benefits of Vegetarian Diets?
Why Some Nutrients Are at Risk of Deficiency in Vegetarian Diets
How to Plan A Healthy Vegetarian Diet

(©iStockphoto)

CASE STUDY

Elliot thinks that it will be better for his health if he stops eating animal products. He is a college student who eats some of his meals at the dining halls and cooks his other meals. He doesn't know much about nutrition, but he knows that the dining halls offer vegetarian choices at every meal. What he doesn't realize is that, although their vegetarian meals don't contain meat, many contain eggs and dairy products. He had planned to eliminate these from his diet as well as meat.

In starting his new eating plan, Elliot thought breakfast would be easy, but as he poured himself a bowl of cereal, he realized that milk was an animal product so he made a note to pick up some soymilk. He decided on toast instead, and since the butter he had in the refrigerator was an animal product, he had peanut butter on his toast. He likes cream in his coffee, but when he read the label on his nondairy creamer he was astonished to find that it contained milk protein. Tomorrow he will use soymilk in his coffee. For lunch he has a veggie and cheese sub, without the cheese. This meal wasn't very filling, so on the way home he bought a big bag of chips—at least these didn't contain any animal products.

For dinner that night the dining hall had vegetarian lasagna, but it was full of cheese. So he just had some pasta with marinara sauce and a salad. Ice cream for dessert was out so he opted for a slice of apple pie once he was assured it didn't contain any animal products. **By the end of the day, he was frustrated and hungry and wondered whether his vegan diet would provide enough protein and other nutrients to keep him healthy.**

© Chris Schmidt/iStockphoto

Outcome

Outcome, appearing at the end of each chapter, completes the case study stories begun in the chapter introduction. For example, the outcome at the end of Chapter 6 describes how the student is able to find more varied vegan choices once he understands complementary proteins and recognizes the variety of healthy ethnic vegan choices that are available to him. The outcome in Chapter 9 describes how the vitamin D deficiency is treated and can be prevented. These "outcomes" review concepts covered in the chapter and illustrate the application of nutrition knowledge to clinical situations.

OUTCOME

Elliot did some reading about vegan diets that helped him understand the plant food combinations that would give him enough protein and other nutrients to meet his needs. He now knows that his peanut butter and toast breakfast is an inexpensive source of complementary proteins. He continues to explore the variety of vegan options offered at ethnic restaurants. The Chinese take-out place near campus has a tasty tofu and vegetable stir-fry and the Indian restaurant offers a number of vegan options that contain lentils or chickpeas with rice or naan (a type of Indian bread). At home he eats lots of salads and vegetables with rice. After spending a little extra time at the grocery store, he discovers almond and rice milks in addition to soymilk that are options for his cereal and coffee. He also discovers vegan prepared foods such as veggie burgers and frozen enchiladas. All these choices give him a varied diet that provides plenty of protein, vitamins, and minerals, and has less saturated fat and more fiber than his former diet. **He now knows how to easily find foods that fit in with his vegan diet. He is enjoying his meals and feels good about the health benefits of his diet.**

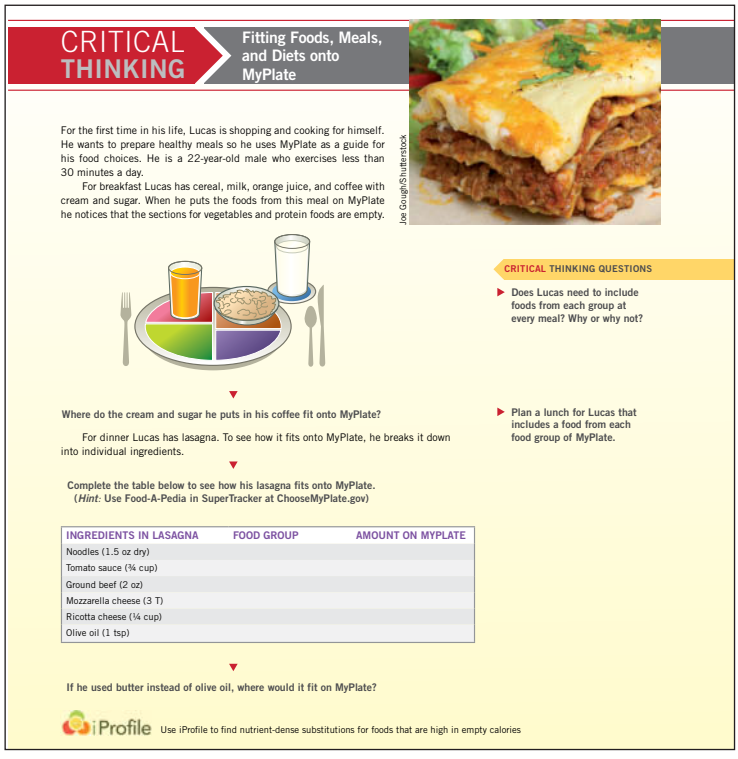
Learning Objectives

Each chapter section begins with one or more learning objectives that indicate, in behavioral terms, what the student must be able to do to demonstrate mastery of the material in the chapter.

4.4 Carbohydrates in the Body

LEARNING OBJECTIVES

- Name the main function of glucose in the body.
- Discuss factors that affect blood glucose levels after eating and when fasting.
- Describe the steps involved in metabolizing glucose to produce ATP.
- Explain how metabolism changes when carbohydrate is limited.



CRITICAL THINKING — Fitting Foods, Meals, and Diets onto MyPlate

For the first time in his life, Lucas is shopping and cooking for himself. He wants to prepare healthy meals so he uses MyPlate as a guide for his food choices. He is a 22-year-old male who exercises less than 30 minutes a day.

For breakfast Lucas has cereal, milk, orange juice, and coffee with cream and sugar. When he puts the foods from this meal on MyPlate he notices that the sections for vegetables and protein foods are empty.

Joe Gough/Shutterstock

Where do the cream and sugar he puts in his coffee fit onto MyPlate?

For dinner Lucas has lasagna. To see how it fits onto MyPlate, he breaks it down into individual ingredients.

Complete the table below to see how his lasagna fits onto MyPlate. (*Hint:* Use Food-A-Pedia in SuperTracker at ChooseMyPlate.gov)

INGREDIENTS IN LASAGNA	FOOD GROUP	AMOUNT ON MYPLATE
Noodles (1.5 oz dry)		
Tomato sauce (¾ cup)		
Ground beef (2 oz)		
Mozzarella cheese (3 T)		
Ricotta cheese (¼ cup)		
Olive oil (1 tsp)		

If he used butter instead of olive oil, where would it fit on MyPlate?

CRITICAL THINKING QUESTIONS

- Does Lucas need to include foods from each group at every meal? Why or why not?
- Plan a lunch for Lucas that includes a food from each food group of MyPlate.

iProfile Use iProfile to find nutrient-dense substitutions for foods that are high in empty calories

Critical-Thinking

These exercises, which appear in each chapter, ask students to use critical thinking to make decisions and solve problems regarding nutrition. They help students apply their nutrition knowledge to everyday situations by presenting a nutrition-related problem and then asking a series of fact-finding and critical thinking questions that lead the student through the logical progression of thought needed to collect information and solve the problem. Many of these exercises focus on modifying a diet to reduce disease risk or maintain health. For example, the exercise in Chapter 2 focuses on how the food choices of a 22-year-old man can fit on MyPlate and how to use this tool to plan a healthy diet. In Chapter 11, Critical-Thinking takes students through the process of assessing the risk of osteoporosis and modifying a diet to increase calcium intake.

OFF THE LABEL

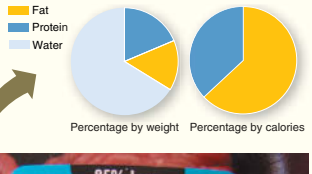
Making Sure Your Meat Is Lean

Looking for lean meat? Most fresh meats (whole cuts and ground and chopped products) are required to have a Nutrition Facts label on the package or have the equivalent nutrition information displayed nearby, but the information related to fat content can still be misleading.[73] Understanding the terminology can help you choose meats that will fit into your diet plan.

The terms "lean" and "extra lean" describe the fat content of packaged meats such as hot dogs and lunch meat, as well as fresh meats such as pork chops and steaks. "Lean" means the meat contains less than 10% fat by weight, and "extra lean" means it contains no more than 5% fat by weight. Ground beef is an exception to these labeling rules. The USDA allows ground beef to be labeled "lean" even if as much as 22% of its weight is fat. To further complicate your shopping, the amount of fat in ground beef labeled "lean" and "extra lean" can vary from store to store.

You can still figure out how much fat is in lean ground beef because ground meats labeled "lean" or "extra lean" must indicate the actual percentage of fat versus lean by stating that it is a certain "% lean" and "% fat" (see figure). So a package of ground beef like this one that is 85% lean and only 15% fat looks like a good choice. But these percentage claims can be misleading. "Percent lean" and "percent fat" refer to the weight of the meat that is lean or fat. So in a meat that is 85% lean, 85% of the weight is lean tissue and 15% of the weight of the meat is fat, so there are 15 g of fat in 100 g (3.5 oz) of raw hamburger. This is a relatively small percentage by weight, but because fat contains 9 kcal/g, the fat contributes 63% of the calories in the meat (see pie charts).

Should you pass on the ground beef and select ground turkey instead? Check the label. If the package is labeled "ground turkey," it may contain skin and leg meat and actually have more fat (about 15 to 20% by weight) than lean ground beef. Only poultry labeled "ground turkey (or chicken) breast" is made with just the lean breast meat and contains only about 3% fat by weight.



Courtesy Mary Grosvenor

THINK CRITICALLY: If you want to purchase ground beef that fits the definition of "lean" meat, what "% lean" should you look for on the label?

Off the Label

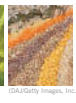
"Off the Label" boxes present in-depth information on food, supplement, and even drug labels. Off the Label is designed to show students how to use labels to make wise choices. For example, the Off the Label in Chapter 4 shows how to use the ingredient list to choose whole-grain products and avoid foods that are high in added sugars. The one in Chapter 9 helps students use the information on Supplement Facts labels to make safe supplement decisions, and in Chapter 10, the Off the Label box discusses the sodium and potassium content of packaged foods and shows students how to use food labels to select foods that are low in sodium and high in potassium.

Science Applied

These boxed features included in every chapter focus on research studies that are key to our current knowledge of nutrition and our understanding of nutrition-related diseases. These help students appreciate how science is done and how the results apply to our understanding of nutrition and medicine. For example, the Science Applied in Chapter 8 discusses how studying the niacin-deficiency disease pellagra led to the enrichment of grains, and in Chapter 9 it describes how studying a bleeding disorder in cattle led scientists to a better understanding of vitamin K and coagulation. Other Science Applied topics include how weightlessness in space contributes to our grasp of osteoporosis, how the discovery of the leptin gene enhanced our understanding of the genetics of body weight regulation, and how the discovery of LDL receptors, which help remove LDL cholesterol from the blood, led to medications to treat high blood cholesterol.

SCIENCE APPLIED

Bone: Lost in Space



When John Glenn became the first American to orbit the Earth in 1962, there was little concern about the effect his five-hour flight would have on his bones. But by 1997, when Shannon Lucid spent 188 days aboard the Russian *Mir* space station, the effect of weightlessness on bone health had become a serious concern. Weight-bearing activities such as walking, jogging, and weight training are important for the maintenance of bone health. Under the force of Earth's gravity, these activities mechanically stress the bones, and this stimulates the deposition of calcium. When an astronaut goes into space, weightlessness eliminates this stimulus, calcium no longer accumulates in bone, and that present in bone upon leaving Earth's gravitational field begins to dissipate, elevating calcium levels in the rest of the body. This may lead to kidney stones and calcification of the soft tissues.[23] Unless bone loss in space can be prevented, prolonged space flights may not be possible.

NASA astronaut Dan Burbank exercises using the advanced Resistive Exercise Device (aRED) in the *Tranquility* node of the International Space Station.

THE SCIENCE

Information on bone loss in space has been accumulating for 60 years. Studies done in the 1960s and early 1970s during the *Gemini* and *Apollo* space missions first showed that astronauts lost calcium from their bones during space travel. *Skylab* missions then offered an opportunity to study the effects of more extended periods in zero gravity. In one study, nine astronauts maintained a constant dietary intake and made continuous urine and fecal collections for 21 to 31 days before their flight, during their *Skylab* missions, and for 17 to 18 days after returning to Earth. The results showed that urinary calcium losses were increased during the flight. These losses occurred despite vigorous exercise regimens while in flight and were comparable to losses seen in normal adults subjected to prolonged bed rest.[24]

In the 1990s, the *Mir* space station provided an opportunity for long-duration studies of bone metabolism in space.[25] The use of dual-energy X-ray absorptiometry (DXA) scans of astronauts and cosmonauts revealed that bone mineral density was decreasing at a rate of about 1.0 to 1.5% per month.[26] The most significant bone loss was found in weight-bearing parts of the skeleton: the lower vertebrae, hips, and upper femur—the same areas at risk for fracture in osteoporosis.[27] Once the astronauts returned to Earth, calcium loss slowed, but even after six months, bone mass in most subjects had not completely recovered.[28] Biochemical measures indicate that the bone loss that occurs during space flight is due to an increase in bone resorption and decreased intestinal calcium absorption.[23,25] The decrease in calcium absorption is likely due to low levels of vitamin D from insufficient dietary intake and lack of ultraviolet light exposure during space flight.[25]

In 2000, the first crews occupied the International Space Station, which was equipped with special resistance exercise equipment. The diet aboard the station provides 1000 to 1200 mg of calcium/day, as is recommended on Earth. Crews on *Skylab* consumed only about 900 mg/day.[29] It has also been determined that supplements of 800 IU/day of vitamin D maintain vitamin D levels during a six-month space mission.[30]

THE APPLICATION

By combining good nutritional intakes with heavy resistance exercise using a treadmill, cycle, and high-load resistance exercise devices (see photo), astronauts aboard the International Space Station were able to maintain their bone mineral density at preflight levels.[30] This occurred because the regimen increased bone formation. It failed, however, to decrease the space flight–induced bone resorption, leaving concerns about bone strength. Studies on astronauts continue to investigate other nutritional factors that affect bone metabolism such as omega-3 fatty acid intakes and appropriate levels of vitamin K, sodium, and protein.[29] What is optimal for bone health in space may be different from what is best for a healthy person living on Earth, but may be applicable to special populations at increased risk of bone loss. Understanding how to optimize nutrient intake and exercise patterns for bone mineral retention during long space flights will not only enhance our potential for space exploration, but also help people who are at risk of bone loss due to prolonged bed rest because of surgery, serious illness, or complications of pregnancy and those who are experiencing immobilization of some part of the body because of stroke, fracture, spinal cord injury, or other chronic conditions.

Debate

The "Debate" features are essays that explore controversial nutrition issues and ask students to think critically about them. Both sides of the issues are presented and then Think Critically questions at the end ask students to integrate and evaluate the information presented. Debates address topics such as "How Involved Should the Government Be in Your Food Choices?" "Is There a 'Best' Diet for You?" "Should You Be Gluten Free?" "Should You Avoid High-Fructose Corn Syrup?" "Is Surgery a Good Solution to Obesity?" and "The Highs and Lows of High-Protein Diets."

DEBATE

How Involved Should the Government Be in Your Food Choices?

The typical U.S. diet is not as healthy as it could be. Poor dietary habits in the United States have resulted in an unfit, unhealthy nation. Our overindulgence has contributed to our high rates of obesity, diabetes, high blood pressure, and heart disease.[4] This is the concern not only of the individuals whose lives it affects but also of the government. The dollar cost to our health-care system is huge; half of the $147 billion per year the United States spends on obesity comes from government-funded Medicare and Medicaid.[5] Government concern is not just financial. The fact that almost one in four applicants to the military is rejected for being overweight is suggested as a threat to national security and military readiness.[6] So, who is responsible for our unhealthy diet, and who should be responsible for changing what we eat?

Joe Raedle/Getty Images

New York City officials tried unsuccessfully to prohibit restaurants, sports stadiums, movie theatres, and food carts from selling sugar-sweetened beverages larger than 16 oz.

Because of the financial and societal costs of an unfit nation, some argue that the government should be more involved in directing our dietary choices. Proponents of more government involvement in our food choices suggest that our food environment is the cause of our unhealthy eating habits. Obesity expert Kelly Brownell believes that environment plays a more powerful role in determining food choices than does personal irresponsibility.[7] Brownell and other proponents of government intervention argue that the government should treat our noxious food environment like any other public health threat and develop programs to keep us safe and healthy. Just as government regulations help to ensure that our food is not contaminated with harmful bacteria, laws could ensure that what you order at a restaurant will not contribute to heart disease or cancer. Unfortunately, unlike bacteria, individual foods are difficult to classify as healthy or unhealthy. Almost all food has some nutritional benefits, and arguments are ongoing as to what is a "junk food" and what we should add or subtract from our diets. However, many people believe there are things that could be done to ensure healthier choices.

One option to encourage healthier choices suggested by proponents of government intervention is to tax junk food, making it more expensive, and increase subsidies for fruits and vegetables, making them less expensive. Another is to control what can be sold. For example, in 2013 New York City's Board of Health attempted to prohibit the sale of sugar-sweetened drinks in cups larger than 16 ounces (oz) (see photo). The courts overturned the ban on the grounds that it exceeded the Board of Health's regulatory authority. Other suggestions to change the food environment include zoning restrictions to keep fast-food restaurants away from schools and limitations on the types of foods advertised on children's television. All these ideas have pros and cons, and none will absolve individuals of the responsibility for getting more exercise and making healthier food choices.

Opponents of government involvement believe such regulation is an infringement on personal freedom and suggest that individuals need to take responsibility for their actions. They propose that the food industry work with the public to make healthier food more available and affordable. Many food companies have already responded to the need for a better diet; General Mills and Kellogg's offer whole-grain cereals. And the giant food retailer Wal-Mart is working with suppliers to reduce the amount of sodium and added sugar and eliminate *trans* fat from packaged foods.

Our current food environment makes unhealthy eating easy. Opportunities for fatty, salty, and sweet foods are available 24/7, and the portions offered are often massive. To preserve our public health, the United States needs to change the way it eats. This change could be driven by government regulations and taxes, it could come from changes in the food industry, or it could come from individuals taking more responsibility for their choices and their health. A synergy of policy intervention, industry cooperation, and personal efforts is likely needed to solve the crisis.

THINK CRITICALLY: Do you think restricting the size of sodas sold will help curb obesity? Why or why not?

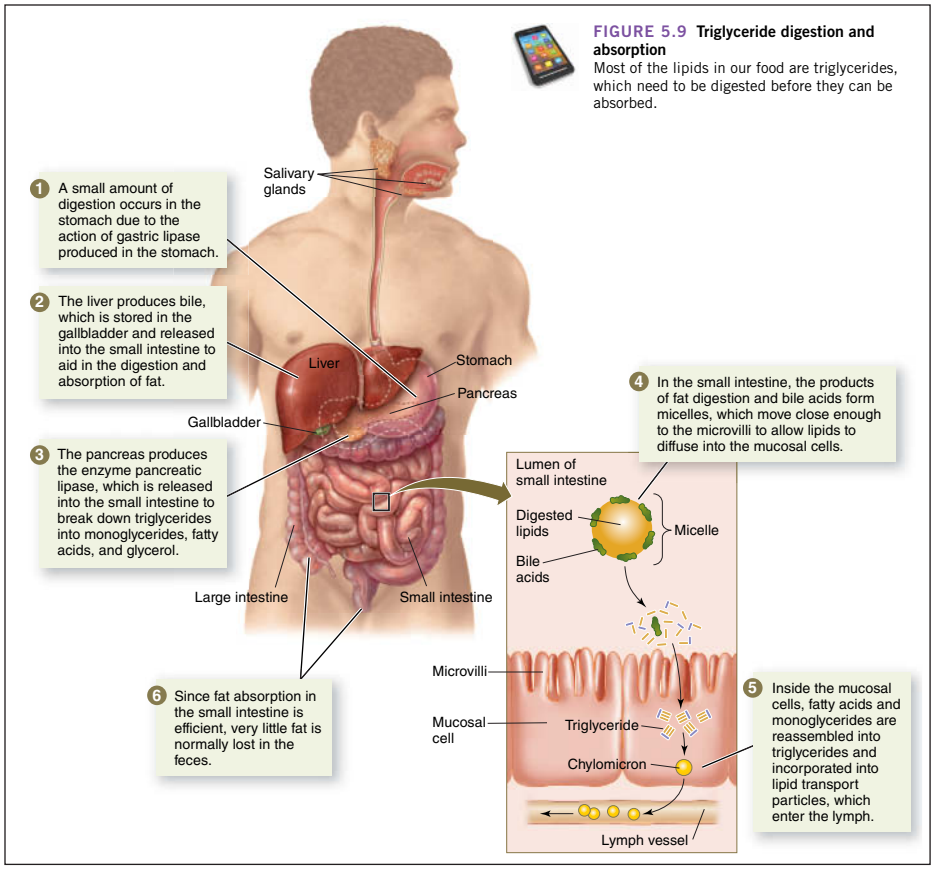


FIGURE 5.9 Triglyceride digestion and absorption
Most of the lipids in our food are triglycerides, which need to be digested before they can be absorbed.

Process Diagrams

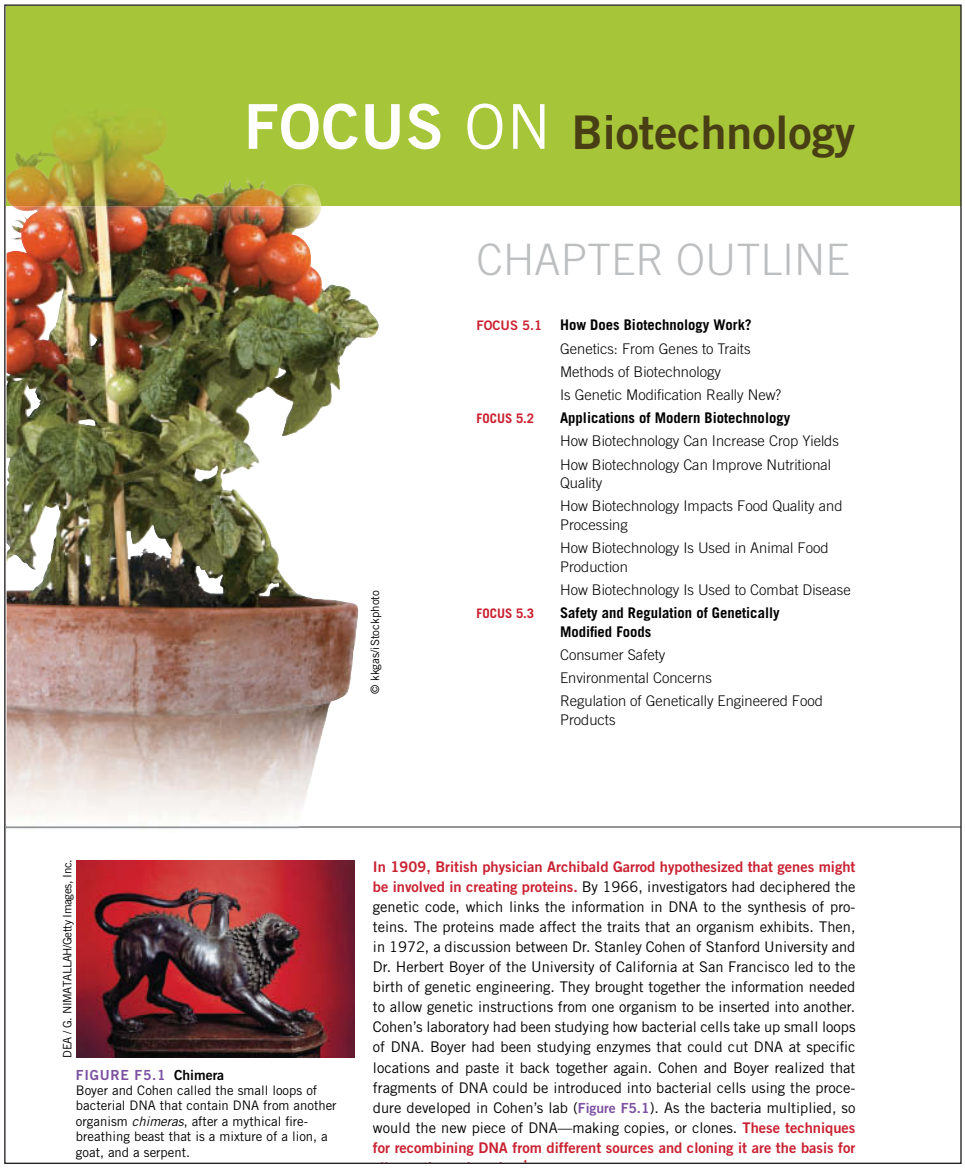
Sometimes the hardest part of understanding a graphic is knowing where to start. To help students comprehend the more complex illustrations, each step in the process depicted is numbered and includes a narrative describing what happens. Process diagrams help students reduce intimidating topics such as digestion and absorption, metabolism, and lipid transport to a series of easy-to-follow steps.

Chapter Summary

Each chapter ends with a summary that highlights important concepts addressed in each section of the chapter.

Focus On

The text includes six Focus On "mini-chapters": Focus on Alcohol, Focus on Eating Disorders, Focus on Phytochemicals, Focus on Dietary Supplements, and Focus on Biotechnology are in the printed text, and Focus on Metabolism is available online. Those in the text discuss topics of great interest to students that are not necessarily part of the core curriculum in nutrition. For example, eating disorders have nutritional symptoms but are really psychological disorders; alcohol is consumed in the diet and affects nutrient metabolism, but is not itself a nutrient; and herbal supplements are not nutrients but may affect health and are sold alongside vitamin and mineral supplements. To provide adequate coverage of these fascinating topics, they are discussed in separate Focus On sections. These sections allow instructors to cover this material or skip it if they feel it is not pertinent to their curriculum. The online Focus on Metabolism is provided for those who want to cover nutrition and metabolism in one chapter rather than, or in addition to, integrating it throughout the text.



FOCUS ON Biotechnology

© ivkgas/iStockphoto

CHAPTER OUTLINE

FOCUS 5.1 **How Does Biotechnology Work?**
Genetics: From Genes to Traits
Methods of Biotechnology
Is Genetic Modification Really New?
FOCUS 5.2 **Applications of Modern Biotechnology**
How Biotechnology Can Increase Crop Yields
How Biotechnology Can Improve Nutritional Quality
How Biotechnology Impacts Food Quality and Processing
How Biotechnology Is Used in Animal Food Production
How Biotechnology Is Used to Combat Disease
FOCUS 5.3 **Safety and Regulation of Genetically Modified Foods**
Consumer Safety
Environmental Concerns
Regulation of Genetically Engineered Food Products

DEA / G. NIMATALLAH/Getty Images, Inc.

FIGURE F5.1 **Chimera**
Boyer and Cohen called the small loops of bacterial DNA that contain DNA from another organism *chimeras*, after a mythical fire-breathing beast that is a mixture of a lion, a goat, and a serpent.

In 1909, British physician Archibald Garrod hypothesized that genes might be involved in creating proteins. By 1966, investigators had deciphered the genetic code, which links the information in DNA to the synthesis of proteins. The proteins made affect the traits that an organism exhibits. Then, in 1972, a discussion between Dr. Stanley Cohen of Stanford University and Dr. Herbert Boyer of the University of California at San Francisco led to the birth of genetic engineering. They brought together the information needed to allow genetic instructions from one organism to be inserted into another. Cohen's laboratory had been studying how bacterial cells take up small loops of DNA. Boyer had been studying enzymes that could cut DNA at specific locations and paste it back together again. Cohen and Boyer realized that fragments of DNA could be introduced into bacterial cells using the procedure developed in Cohen's lab (Figure F5.1). As the bacteria multiplied, so would the new piece of DNA—making copies, or clones. **These techniques for recombining DNA from different sources and cloning it are the basis for**

Margin Features

The text includes a number of features that are placed in the margin. These aid comprehension, enhance interest, and point out where particular types of information can be found.

Definitions of New Terms

New terms are highlighted in bold in the text and defined in the margin, providing easy access to new terms as they appear. These and other terms are included in an extensive glossary at the back of the text.

Carbohydrate Digestion and Absorption

Digestion of carbohydrate begins in the mouth, where the enzyme salivary amylase starts breaking starch into shorter polysaccharides. The majority of starch and disaccharide digestion occurs in the small intestine. Here, pancreatic amylases complete the job of breaking down starch into disaccharides and oligosaccharides. The digestion of disaccharides and oligosaccharides is completed by enzymes attached to the microvilli in the small intestine (Figure 4.9). Here maltose is broken down into two glucose molecules by the enzyme maltase, sucrose is broken down by sucrase to yield glucose and fructose, and lactose is broken down by **lactase** to form glucose and galactose. The resulting monosaccharides—glucose, galactose, and fructose—are then absorbed and transported to the liver via the hepatic portal vein.

lactase An enzyme located in the microvilli of the small intestine that breaks the disaccharide lactose into glucose and galactose.

iProfile Icons These show students where they can use the iProfile software to answer a nutrition-related question.

Video Icons These icons appear by topics that students can explore further by watching a BBC, **New York Times**, CBS, or Voice of America video in WileyPLUS Learning Space.

Metabolism Icons These highlight discussions of how each nutrient fits into the metabolic processes of nutrition.

Life cycle Icons These highlight discussions of the differences in nutritional requirements, concerns, and effects at different life stages. This information helps students understand how nutrient requirements are affected by life stage as well as offering information relevant to students in all phases of life. **Life cycle** nutrition is also covered in depth in Chapters 14, 15, and 16.

Hear This Illustration Icons These indicate important figures with accompanying audio files within WileyPLUS Learning Space. Narrated tutorials help students understand more complex topics while they review these figures.

New to This Edition

Most Current Information

As the science of nutrition continues to evolve *Nutrition Science and Applications* evolves with it, to include the most up-to-date information, terminology, and ways of thinking about nutrition. The entire text has been updated and re-referenced to reflect the most current nutrition science and guidelines. More information on the emerging science of nutritional genomics, nutritional programming, the recognition of non-celiac gluten sensitivities, and the role of the intestinal microbiota in human health has been added. Current recommendations in nutrition, such choosing a plant-based diet and reducing added refined sugars have been integrated into discussions of diet and health and advances in our understanding of biotechnology and the effect of our food environment on the incidence of non-communicable nutrition-related diseases has been addressed. The most recent information is included on the prevalence of obesity and undernutrition as well as programs such as Healthy People 2020 and the United Nations 2015 Sustainable Development Goals that target improving health and nutrition.

2015–2020 Dietary Guidelines

This up-to-date text includes the recommendations of the *2015–2020 Dietary Guidelines for Americans*, which are described in Chapter 2 and addressed in all applicable subsequent chapters.

FIGURE 2.7 Healthy eating patterns
The Dietary Guidelines for Americans suggest that there are many ways to choose a healthy diet. Healthy dietary patterns all focus on similar types of foods, but choices can be tailored to suit an individual's preferences and meet their medical needs (see Appendices B and C for more information).

The DASH Eating Plan

Food group	Servings
Grains	6–8/day
Vegetables	4–5/day
Fruits	4–5/day
Fat-free or low-fat milk and milk products	2–3/day
Lean meats, poultry, and fish	6 or less/day
Nuts, seeds, and legumes	4–5/week
Fat and oils	2–3/day
Sweets and added sugars	5 or less/week

The DASH Eating Plan is plentiful in fruits and vegetables, whole grains, low-fat dairy products, fish, poultry, seeds, and nuts. It was first developed for lowering blood pressure (see Chapter 10).

USDA Food Patterns

Food group	Amount/day
Vegetables	2.5 cups
Fruit and juices	2.0 cups
Grains	6.0 ounces
Dairy products	3.0 cups
Protein foods	5.5 ounces
Oils	27 grams
Solid fats	16 grams
Added sugars	32 grams

Mediterranean Eating Pattern

Foods	How often
Fruits, vegetables, grains (mostly whole), olive oil, nuts, legumes and seeds, herbs and spices	Every meal
Fish and seafood	At least twice a week
Cheese and yogurt	Moderate portions daily or weekly
Poultry and eggs	Moderate portions every 2 days or weekly
Meats and sweets	Less often

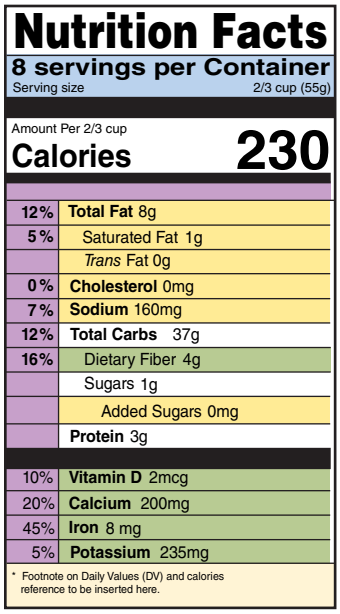
Traditional Mediterranean eating patterns are based on fruits, vegetables, grains, olive oil, fish, beans, nuts, legumes, and seeds. They include smaller amounts of red meat and sweets. The incidence of chronic diseases such as heart disease is low in populations consuming these diets (see Chapter 5).

USDA Vegetarian Adaptations

Food group	Amount/day	
	Lacto-Ovo	Vegan
Dairy products or dairy substitutes	3 cups milk, calcium fortified soymilk, or yogurt, 4½ oz. hard cheese	3 cups calcium fortified soymilk or other plant-based milks or yogurts
Protein foods		
Eggs	4 per week	
Beans and Peas	⅓ cup	½ cup
Soy products	½ cup tofu, 2 oz. tempeh, ½ cup soybeans	½ cup tofu, 2 oz. tempeh, ½ cup soybeans
Nuts and Seeds	¼ cup	¼ cup

The USDA Food Patterns and their vegetarian adaptations suggest amounts of foods from different food groups for different calorie levels (2000 kcal shown here). These were developed to help individuals follow the Dietary Guidelines and are the basis for the MyPlate recommendations.

Food Labeling



The FDA has proposed updates to the Nutrition Facts labels we see on most packaged foods. Coverage of this topic in Chapter 2 compares the current food label to the proposed Nutrition Facts label. The relevance of these proposed changes is also addressed in all applicable subsequent chapters. Although these labels have not been adopted, they offer a launching pad for student discussion and critical thinking regarding the purpose of food labels and the effectiveness of current food labels in providing consumer guidance, and how best to present nutrition information about individual foods to consumers.

In addition to this information on the labeling of packaged foods, the most up-to-date information on the calorie labeling of foods sold at restaurants and in vending machines is included.

New Health Management Guidelines

Recently published guidelines for the management of cardiovascular disease, blood pressure, and overweight and obesity have been integrated into Chapters 5, 10, and 7, respectively. New diagnostic criteria for eating disorders are included in Focus on Eating Disorders and new diagnostic criteria for alcohol use disorder, commonly known as alcoholism, are included in Focus on Alcohol. The World Health Organization's infant growth charts, which are now recommended for infants in the United States, are included in Chapter 14. The recommendations of the Healthy Hunger-Free Kids Act regarding school lunch standards are discussed in Chapter 15, and new recommendations on protein intake in older adults to minimize lean tissue loss are included in Chapter 16. Updated guidelines for fish consumption for children and pregnant women are discussed in Chapter 17.

Choice (Exchange) Lists

The Choice Lists, which update and replace the Exchange Lists, are discussed in Chapter 2, and revisited in Chapters 4, 5, and 6, which address the energy-yielding nutrients, and with energy balance in Chapter 7. The complete Food (Exchange) Lists are provided in the online appendices.

New and Updated Features

Many of the Debate, Off the Label, and Science Applied features in the Fourth Edition, have been amended and updated and new topics have been introduced. The chapter Case Study introductions and Outcome stories have been gently edited to make them more student friendly.

A few new Debate topics have been introduced and all have been revised to include the most up-to-date science. The Chapter 1 Debate, "Is There a 'Best' Diet for You?" which focuses on the new science of nutritional genomics, has been rewritten and new art added to enhance student understanding of this topic. The Chapter 3 Debate, "Should You Be Gluten Free?" has been updated to include a discussion of non-celiac gluten sensitivity. A new Debate on coconut oil, "Coconut Oil: Does a Tablespoon a Day Keep the Doctor Away?" has been included in Chapter 5 to highlight the conflicting information about this type of lipid. The Chapter 12 Debate, "Antioxidant Supplements: Helpful or Harmful?" has been rewritten and new art added to explain the concept of oxidative stress. The Chapter 6 Debate, "The Highs and Lows of High-Protein Diets," has been revised to provide the most current information on the risks and benefits of high-protein diets.

A few of the Off the Label features are new, and most have been updated to include the proposed label changes. In Chapter 1, a new Off the Label "Beware of Misleading Claims"

focuses on how manufacturers use label claims to promote product sales. In Chapter 7, the Off the Label has been revised to highlight the proposed changes in serving sizes and how the number of calories is presented on the label and in Chapter 11, a new Off the Label, "How Much Calcium Is in Your Yogurt?" shows changes in the presentation of micronutrients on the proposed label.

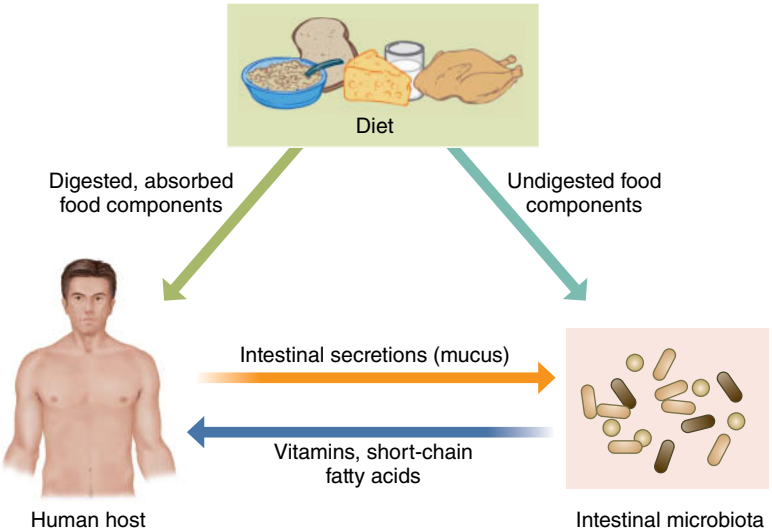
Where appropriate, the Science Applied features have been revised to include continued advances in science. For example, in Chapter 16, "Eat Less–Live Longer" has been updated to include the most recent research on calorie restriction. In Chapter 11, "Bones: Lost in Space" includes information on advances in nutrition and exercise regimens for astronauts aboard the International Space Station.

Improved Critical Thinking Exercises

Critical Thinking topics have been refined and the design modified slightly to distinguish fact-gathering questions from those that require true critical thinking. Critical thinking is a process that challenges an individual to use reflective, reasonable, rational thinking to gather, interpret, and evaluate information in order to derive a judgment. These exercises start by giving students background information and identifying a nutritional problem. Students then use the clinical data provided, such as blood cholesterol values, body weight, or diet records, to first gather information and then answer a series of critical-thinking questions to explore and solve the problem.

In addition to refining the critical thinking in these exercises, many of the Think Critically questions linked to art and special features have been refined and Analyze the Data questions have been added to enhance students' ability to analyze the information presented in graphs and charts.

New and Improved Art



In *Nutrition: Science and Applications,* Fourth Edition, the new art program introduced in the previous edition continues to be improved and refined to enhance clarity, understanding, and visual appeal. New illustrations and photographs have been added to enhance student understanding and make important visual points. For example, Chapter 1 includes two new graphs: one showing how the amount of time we spend cooking has changed since 1965 and another showing how eating breakfast away from home impacts overall diet quality. Additional new art in Chapter 1 helps illustrate the science of nutritional genomics. In Chapter 2, the figure on healthy dietary patterns has been updated to include vegetarian dietary patterns and the proposed Nutrition Facts label has been added so it can be compared to the current label. In Chapter 3, new art helps students understand the role of the intestinal microbiota in overall health. Chapter 6 introduces an illustrated table to distinguish different types of vegetarian diets and a new illustration to show how to use MyPlate to plan vegetarian and vegan diets. Chapter 7 includes the most recent obesity map, a new figure to illustrate the role of nonexercise activity thermogenesis (NEAT) in regulating body weight, and a new decision tree illustration for determining who should lose weight based on the most recent guidelines for the treatment of overweight and obesity. Chapter 12 has new art in the Debate to illustrate oxidative stress. New art in Chapter 13 highlights the relationship between nutrition, physical activity, and health and new art in Chapter 18 illustrates the impact of infectious disease on child deaths and the impact of noncommunicable diseases on a population's productivity.

Chapter-by-Chapter Overview

CHAPTER 1—"Nutrition: Food for Health," begins by discussing why we eat what we do, how the American diet has changed, and how healthy it is. It emphasizes that food choices affect current and future health. This chapter provides an overview of the nutrients and their roles in the body, and defines the basic principles of balance, variety, and moderation that are key to a healthy diet. It also introduces the scientific method and the steps students need to follow to sort accurate from inaccurate nutrition information.

CHAPTER 2—"Nutrition Guidelines: Applying the Science of Nutrition," takes the science out of the laboratory and shows how advances in nutrition knowledge have been used to develop the Dietary Reference Intakes (DRIs), the *Dietary Guidelines for Americans*, and tools for diet planning, including MyPlate, food labels, and Choice (Exchange) Lists. The final section of this chapter discusses how these and other tools can be used to assess the nutritional health of populations and individuals.

CHAPTER 3—"Digestion, Absorption, and Metabolism," discusses how food is digested, how nutrients from foods are absorbed into the body and transported to the cells where they are broken down to provide energy or used to synthesize structural or regulatory molecules, and finally how wastes are removed. This chapter provides an overview of metabolism that serves as a launching pad for the more detailed metabolism information presented in subsequent chapters.

CHAPTER 4—"Carbohydrates: Sugars, Starches, and Fiber," begins with a discussion of the sources and types of carbohydrates in our food. The chapter discusses carbohydrate digestion, absorption, and metabolism and the functions of carbohydrates in the body. The health impact of refined grains and added sugar versus whole grains and unrefined sources of sugars are discussed. The role of dietary carbohydrate in the management of health conditions such as diabetes, dental caries, obesity, heart disease, diverticulosis, and colon cancer are discussed. The chapter ends with a discussion of how to choose a diet that meets carbohydrate recommendations.

CHAPTER 5—"Lipids: Triglycerides, Phospholipids, and Cholesterol," discusses the basics of lipid digestion, absorption, transport, and metabolism, and explains how lipids function in the body. The discussion on fats in our food addresses the sources of fat in our diet and points out that Americans are not eating too much fat, but are typically choosing the wrong types of fat for a healthy diet. The chapter also explains the steps involved in the development of cardiovascular disease and discusses the relationship between fat intake and the risk of cardiovascular disease, obesity, and cancer. The chapter ends with a discussion of how to choose a diet that meets lipid recommendations.

FOCUS ON ALCOHOL discusses alcohol metabolism, the health risks associated with excessive alcohol consumption, and the health benefits associated with moderate intake.

CHAPTER 6—"Proteins and Amino Acids," discusses animal and plant sources of protein and points out that either plant or animal proteins can meet protein needs, but these protein sources bring with them different combinations of nutrients. In addition to discussing protein digestion, absorption, and metabolism, the chapter explains how amino acids are

used for protein synthesis and the functions of the proteins synthesized in the body. The chapter includes information on protein deficiency and excess and recommendations on meeting protein needs and planning healthy vegetarian diets.

CHAPTER 7—"Energy Balance and Weight Management," discusses the obesity epidemic and its causes, and the effects of excess body fat on health. The chapter explains energy balance and shows how small changes in diet and behavior can alter long-term energy balance. The most up-to-date information on how body weight is regulated and the role of genetic versus environmental factors in determining body fatness is covered. The chapter includes recommendations for healthy body weight and composition and equations for determining energy needs. It also discusses weight-loss options that range from simple energy restriction to the most common surgical approaches.

FOCUS ON EATING DISORDERS includes a comprehensive discussion of the different types of eating disorders, their causes, consequences, and treatment. This Focus also addresses the sociocultural factors that influence body ideal as well as what to do to help a friend or relative that you suspect has an eating disorder.

CHAPTER 8—"The Water-Soluble Vitamins," begins with a general overview of the vitamins—where they are found in the diet, factors affecting their bioavailability, and how they function. Each of the B vitamins and vitamin C is then discussed individually, providing information on sources in the diet, functions in the body, impact on health, recommended intakes, use as dietary supplements, and potential for toxicity. This chapter also discusses choline, a substance that is not currently classified as a vitamin but one for which DRIs have been established.

CHAPTER 9—"The Fat-Soluble Vitamins," introduces the fat-soluble vitamins within the context of the modern diet and then presents each one with a discussion of its sources in the diet, functions in the body, impact on health, recommended intake, use as a dietary supplement, and potential for toxicity. The chapter ends with a discussion of who needs vitamin and mineral supplements and how to choose them.

FOCUS ON PHYTOCHEMICALS discusses the role of phytochemicals in nutrition and health. These substances are not dietary essentials but can positively impact health. Different categories of phytochemicals are presented, along with a discussion of how to maximize their intake.

CHAPTER 10—"Water and the Electrolytes," addresses water, a nutrient often overlooked, and sodium, potassium, and chloride, because they help regulate the distribution of body fluids. This chapter presents information on where these nutrients are found in the diet and describes their functions in the body and their relationship to health and disease. A discussion of hypertension illustrates the importance of sodium, potassium, and other minerals and dietary components in blood pressure regulation. Advances in our understanding of how dietary patterns affect hypertension are stressed in a discussion of the DASH diet, a dietary pattern that has been shown to lower blood pressure.

CHAPTER 11—"Major Minerals and Bone Health," provides an overview of the minerals and discusses the remaining major minerals, calcium, phosphorus, magnesium, and sulfur. Their functions in the body and availability in the diet as well as their relationship to health and disease are addressed. Because most of these play an important role in bone health, this chapter also includes a section on the relationship between nutrition, bone health, and the development of osteoporosis.

CHAPTER 12—"The Trace Minerals," discusses the trace minerals in a format similar to that used for other micronutrients. Emphasis is placed on the unique roles of some minerals as well as the similarities that some have in their functions and the interactions among them. Discussions of the health issues related to these nutrients help create interest, as do discussions of the pros and cons of trace mineral supplements.

FOCUS ON DIETARY SUPPLEMENTS targets dietary supplements that contain substances other than micronutrients. Micronutrient supplements are discussed in depth in Chapters 8 through 12 with the appropriate nutrient, but many of the supplements Americans are taking include ingredients that are not vitamins or minerals. This Focus will help students evaluate the benefits and risks associated with supplements containing substances such as coenzyme Q and glucosamine that are found naturally in the body, as well as herbal ingredients such as echinacea.

CHAPTER 13—"Nutrition and Physical Activity," begins by discussing the relationships among physical activity, nutrition, and health. It emphasizes the importance of exercise for health maintenance as well as the impact nutrition can have on exercise performance. Because nutrients fuel activity, this chapter serves as a review of energy metabolism. By this point in the text, students have studied all the essential nutrients, so a complete discussion of the macronutrients and micronutrients needed to generate ATP for various types of activity can be included. An expanded discussion of ergogenic aids for more competitive athletes directs students to use a risk-benefit analysis of these products before deciding whether or not to use them.

CHAPTER 14—"Nutrition During Pregnancy and Lactation," addresses the role of nutrition in human development by discussing the nutritional needs of women during pregnancy and lactation as well as the nutritional needs of infants. The benefits of breastfeeding versus formula feeding are discussed.

CHAPTER 15—"Nutrition from Infancy to Adolescence," begins with a discussion of what American children are eating and how it relates to the rising rates of childhood obesity and other chronic diseases. The chapter discusses the nutrient needs and nutrition-related health concerns of children, from infancy through adolescence.

CHAPTER 16—"Nutrition and Aging: The Adult Years," addresses how nutrition affects health and how the physiological changes that occur with aging affect nutritional needs and the ability to meet them. The impact that chronic disease, medications, and socioeconomic changes have on the risk of malnutrition is discussed.

CHAPTER 17—"Food Safety," discusses the risks and benefits associated with the U.S. food supply and includes information on different types of microbial hazards, chemical toxins, food additives, irradiation, and food packaging. This chapter discusses the use of HACCP (Hazard Analysis Critical Control Point) to ensure safe food and the role of the consumer in selecting, storing, and preparing food to reduce the risk of food-borne illness.

FOCUS ON BIOTECHNOLOGY explains how genetic engineering is used to modify the characteristics of organisms and create new products. It addresses the potential benefits and risks associated with this expanding technology.

CHAPTER 18—"World Hunger and Malnutrition," discusses the coexistence of undernutrition with obesity and other non-communicable diseases due to overnutrition in both developed and developing nations around the world. It examines the causes of world hunger and solutions that can impact the amounts and types of food and nutrients that are available.

Teaching and Learning Resources

WileyPLUS Learning Space

WileyPLUS Learning Space is a new dynamic teaching and personalized learning environment that features your course content intuitively organized—all in one place.

With WileyPLUS Learning Space, students have the opportunity to practice, ask questions, share insights and see how they are doing through self-assessment. Students feel more invested in their learning experience as they participate with course topics and each other in meaningful new ways.

What can students do with WileyPLUS Learning Space?

- Access the complete digital textbook and integrated multimedia resources
- Instantly know what they need to work on from their visual dashboard
- Create a personal study plan
- Assess their progress throughout the course with informative reports
- Participate in class discussions
- Remember what they have learned because they have made deeper connections to the content

What can instructors do with WileyPLUS Learning Space?

- Assign activities and add their own materials
- Guide students through what's important in the interactive e-textbook by easily assigning specific content
- Set up and monitor collaborative learning groups
- Assess learner engagement
- Gain immediate insights to help inform teaching with visual reports

Student Resources in WileyPLUS Learning Space

ORION Personalized Practice

ORION asks practice questions to assess student understanding at the objective level and identify areas where more study is needed. This adaptive practice meets students at just above their level in order to keep them challenged, but not frustrated. Adaptive practice includes extensive actionable reports that focus student study in key areas individual to each learner. ORION features a rich question database with nearly 6,000 questions at every level of difficulty on a 100-point, nationally-set difficulty level and all Bloom's levels. All students begin with a unique, short diagnostic quiz that establishes a baseline from which each student develops his own unique path.

Videos

Videos produced by the BBC, CBS, and Voice of America spark discussion and allow students to explore current and relevant topics in nutrition. These videos help students discover relevant and topical issues like diabetes, the local food movement, and gastric bypass surgery.

Video Bites

This new video series features student-focused sketches that explore the impact of day-to-day nutrition choices using real life scenarios. Each video examines a topic germane to one or more chapters and blends up-to-date information with humor to pique student interest, address misconceptions, and spark discussion.

How It Works Animations

Wiley has developed a new set of animations for nutrition students and professors. We surveyed professors across North America to find out what topics were the most difficult to teach and learn and what processes were most essential to the introductory nutrition course. After much research and review, we developed animations on these topics, to make these difficult processes easier for students to understand and bring the process diagrams from the book to life.

- Absorption of Nutrients
- Flow of Blood During Absorption
- Digestion and Absorption of Carbohydrates
- Glucose Metabolism
- Regulation of Glucose Metabolism
- Maintaining Normal Blood Glucose Levels
- Blood Glucose Regulation
- Digestion and Absorption of Lipids
- Lipid Transport
- Metabolism of Lipids
- Digestion and Absorption of Proteins
- Metabolism of Proteins
- Role of B Vitamins in Metabolism
- Action of Antioxidants Against Free Radicals
- How Vitamin C Supports Immune Function
- Acid-Base Balance

Other Animations

In addition to the How It Works animations, many other animations exist to aid student comprehension. These include: MyPlate, Biology Basics, Visualizing Serving Sizes, and Estimating Portion Sizes.

iProfile 3.0: Assessing Your Diet and Energy Balance

The iProfile dietary analysis program now features improved food searches and is available as a mobile-enabled website. Students can access the new **mobile version** on their phone or tablet to conveniently add items to their food journal throughout the day. This dynamic diet assessment software includes nutrient values for over 50,000 foods, inclusive of many of the most popular food choices of students today, as well as ethnic and cultural choices. It includes a feature that allows users to add foods to the database to keep pace with the ever-growing market of available products. Since exercise is such an important part of energy balance, the software also allows students to track and analyze their physical activity. In addition to the ability to track and analyze food intake and exercise, some distinctive features include serving-size animations, a quick self-quiz, single nutrient reports, recipe builder, and an easy-to-use design.

Games and Activities

New to this edition and embedded in the e-textbook, are activities that require mathematical calculations and critical thinking. Some ask students to compute calories and percentages of the RDA and others are drag-and drop games to identify food sources of macro- and micronutrients. Developed by Rose Martin at Iowa State University, these include informative feedback about the health consequences of specific nutrient toxicities or deficiencies. Each activity allows for multiple attempts for continued practice. Additional activities are available at the chapter level and allow students to modify meals and recipes to make healthier choices.

Nutrition Bytes Blog

The Nutrition Bytes Blog provides an ongoing dialogue of current topics and controversies in nutrition. These provide up-to-the-minute discussions on the latest hot topics in nutrition and encourage critical thinking around these. Nutrition Bytes is accessible on mobile devices and available from both the student and instructor companion sites, as well as within WileyPLUS Learning Space. The blog is written by Katie Ferraro of The University of San Diego and updated on a biweekly basis, ensuring that discussions focus on the most current and relevant issues in nutrition. Blogs are searchable for topics of interest and

students and instructors can join the discussion by posting their own comments. Users can subscribe to the newsfeed, which will automatically add it to their Favorites Center and be kept up to date.

Hear This Illustration

Audio tutorials accompany key figures for improved understanding of important topics and are available with downloadable transcripts.

Interactive Process Diagrams and Graphics

Select interactive figures within WileyPLUS Learning Space allow students to learn the concepts presented and then have an opportunity to build the processes themselves.

Applications

These exercises, which are included for each chapter, contain three sets of application questions. The "Assessing Your Diet" applications focus on the student's personal diet and nutrition concerns "Consumer Issues" applications address more general consumer nutrition issues such as reading food labels. The "Clinical Concerns" applications ask about more clinical nutrition and health issues as they relate to the chapter material. All require the student to think critically and apply key nutrition concepts, and all help reinforce the importance of nutrition in health promotion and disease prevention. Some of these can be done as collaborative learning exercises, which encourage students to work together and learn from one another to solve a problem.

Review Questions

A set of questions is available for each chapter to test students' understanding of the key points covered. Students can use them as a study tool to test their comprehension of the important information in the chapter.

Teaching Materials Available to *Instructors*

- **Test Bank**—Available online, the Test Bank includes multiple-choice questions as well as short case studies with questions. Many other question banks are available including pre-populated assignments and the ability to customize your own assignments.
- **Respondus Test Bank**—This computerized version of the Test Bank makes preparing clear, concise tests quick and easy.
- **Nutrition Visual Library**—This resource includes all of the illustrations from the textbook in labeled, unlabeled, and unlabeled with leader line formats. Search for images by chapter, or by using keywords. It is also available through WileyPLUS Learning Space.

iProfile Mobile and iProfile Assignments

The iProfile dietary analysis program now contains a database of over 50,000 foods and is available as a mobile-enabled website. Students can enter their food intakes and activities into their journal on the go via their smart phones and tablets. iProfile is also available, with additional functionality, fully integrated with WileyPLUS Learning Space. WileyPLUS Learning Space includes a few types of assessments around iProfile, including computer gradable **Dietary Analysis Exercises** in Chapters 4 through 9, written by Lori A. Smolin and Mary B. Grosvenor. These exercises ask students to analyze and modify a diet in relation to the specific nutrients discussed in the chapter. iProfile **Case Study** Assignments are available in every chapter. These focus on a specific nutritional concept or dietary pattern related to that chapter's content. Students are asked to enter the food choices of the case study subject and then analyze the impact of these choices. Each case study topic includes a question to generate discussion as well as gradable multiple-choice and true-false questions.

Companion Websites

- **Student Companion Website** [www.wiley.com/college/smolin] A dynamic website rich with many activities for review and exploration includes: Quizzes for each chapter, Flash Cards for learning concepts and terminology, Hear This Illustration podcasts, and the Nutrition Bytes Blog.
- **Instructor Companion Website** [www.wiley.com/college/smolin]—A dedicated companion website for instructors provides many resources for preparing and presenting lectures. Also available are all of the illustrations and tables in the text already placed within PowerPoint Slides, as well as a set of Lecture PowerPoints that combine important images with major concepts from each chapter. Questions for use with Clicker Systems are also provided.

To the Student

Nutrition is a subject that all of you have a personal interest in, whether you are concerned about your own nutritional health, a parent with diabetes, or a friend with an eating disorder. You may enroll in a nutrition course to learn what to eat and how to choose healthy foods and then be surprised when the course talks about protein synthesis, lipid transport, and anaerobic metabolism. A good course and textbook should do both.

As authors, our goal is to provide you with tools that can be used throughout your life. We could tell you what to eat for breakfast, but if you didn't understand why these foods were healthy choices you would not be able to make your own healthy choices from a different set of breakfast foods, or use the same principles to choose a healthy dinner. On the other hand, for example, if you understand how your saturated fat intake can affect your risk for heart disease or your sodium intake affects your blood pressure, you will have the tools you need to choose a healthy dietary pattern.

The critical-thinking approach we have used in this text will help you understand the science of nutrition and give you the decision-making skills you need to navigate the scores of choices you face when deciding what to eat and which of the latest nutrition headlines to believe. By becoming a knowledgeable consumer, you will be able to make informed choices about diet and lifestyle, whether you use this information to improve your own health or to pursue a career in nutrition.

Acknowledgments

We are grateful to the editorial and production staff at John Wiley & Sons for their help and support. We thank our Executive Editor Bonnie Roesch for originally signing this book, our Market Solutions Director Kevin Witt for his constant encouragement, support, and guidance in helping us navigate the nutrition market and overcome obstacles at all stages of production, our Executive Editor Ryan Flahive for his enthusiasm and forward-looking attention to online learning, our Senior Associate Development Editor Lauren Elfers for the endless hours she devoted to creating the text and media for the book and for always being there for crisis management, and our Executive Marketing Manager Clay Stone for his zeal in coordinating the advertising, marketing, and sales efforts for the book and its supplements. We are also grateful to Emma Townsend-Merino for helping bring the project to fruition, our Photo Editor Mary Ann Price for ensuring the outstanding quality of the photos in this text, our designer Wendy Lai for delivering an attractively designed text and cover, and our Production Editor Patricia McFadden and Aptara Senior Production Manager Sherrill Redd for their patience and efficiency in guiding this project through production. We would also like to thank our illustrator Elizabeth Morales, whose creativity, talent, and ability to translate our sketches into understandable visual illustrations continues to elevate the visual impact of the text.

We would like to add a special thank you to John Ambrose, who worked tirelessly to write, direct, and produce Video Bites, a unique set of short videos that help students relate to key topics covered in the text.

The authors wish to offer a special thanks to those who have worked on the preparation of the many resources found on the companion websites and within WileyPLUS. They are Melissa Altman-Traub, Community College of Philadelphia; Melanie Burns, Eastern Illinois University; Katie Ferraro, University of San Diego; Jared Garbutt, American River College; Jennifer Koslo, Mesa Community College; Fran Lukacik, Community College of Philadelphia; Rose Martin, Iowa State University; and Jennifer Zimmerman, Tallahassee Community College.

We are grateful to the following reviewers, survey respondents, and focus-group attendees who offered their comments and suggestions.

Reviewers, Focus-Group Participants, and Survey Respondents

Jeremy Akers, *James Madison University*
Katherine Alaimo, *Michigan State University*
Amy Allen-Chabot, *Anne Arundel Community College*
Sandra Baker, *University of Delaware*
William Banz, *Southern Illinois University*
Gayl Canfield, *Palm Beach State College*
Jennifer Case, *Purdue University Online*
Melissa Chabot, *SUNY at Buffalo*
Anne Cioffi, *Hudson Valley Community College–Troy*
Annette Crawford-Harris, *Hudson Valley Community College–Troy*
Sylvia Crixell, *Texas State University*
James Collins, *University of Florida*
Laura Davidson, *Community College of Philadelphia*
Joanne DeMarchi, *Saddleback College*
Jan Dowell, *Moraine Valley Community College*
Kara Egan, *Indiana University–Purdue University Indianapolis*
Jennifer Ekstrom, *Michigan State University*
Mary Flynn, *Brown University*
Tiffany Garrison, *Gateway Technical College*
Susan Giannakis, *Pensacola State College*
Jana Gonsalves, *American River College*
Sareen Gropper, *Florida Atlantic University*
David Hall, *Kirkwood Community College*
Amber Haroldson, *Ball State University*
DJ Hennager, *Kirkwood Community College*
Carol Impara, *Mt. San Antonio College*

Younghee Kim, *Bowling Green State University*
Agata Kowalewska, *University of Florida*
Paula Mendelsohn, *Palm Beach State College*
Judy Myhand, *Louisiana State University*
Vijaya Narayanan, *Florida International University*
Lynn Parker-Klees, *Pennsylvania State University*
Taylor Puryear, *Barstow Community College*
Eljeanor Quebedeaux, *McNeese State University*
Shahla Ray, *University of Indiana*
Burgin Ross, *University of North Carolina–Greensboro*
Timothy Sassanella, *Macomb Community College*
Elizabeth Sussman, *California State University–Northridge*
Terry Thompson, *Wor-Wic Community College*
Joan Vaccaro, *Florida International University*
Dianne Van Treeck, *Palm Beach State College*
Jen Yang, *Indiana State University*

Nutrition Advisory Board Members

Jeremy Akers, *James Madison University*
Jeanne Boone, *Palm Beach State College*
Nancy Berkoff, *California State University–Chico*
Linda Brown, *University of North Florida*
Melanie Burns, *Eastern Illinois University*
Jayne Byrne, *College of St. Benedict*
James F. Collins, *University of Florida–Gainesville*
Laura Christoph, *Holyoke Community College*
Sylvia Crixell, *Texas State University*
Barbara Goldman, *Palm Beach State College*
Timaree Hagenburger, *Consumnes River College*
Donna Handley, *University of Rhode Island*
Kirsten Hilpert, *State University of New York–Oneonta*
Karen Israel, *Anne Arundel Community College*
Owen Murphy, *Central Oregon Community College*
Judith Myhand, *Louisiana State University*
Cheryl Neudauer, *Minneapolis Community and Technical College*
Shahla Wunderlich, *Montclair State University*

Brief Contents

1 **Nutrition: Food for Health** 3
2 **Nutrition Guidelines: Applying the Science of Nutrition** 33
3 **Digestion, Absorption, and Metabolism** 73
4 **Carbohydrates: Sugars, Starches, and Fiber** 109
5 **Lipids: Triglycerides, Phospholipids, and Cholesterol** 151

FOCUS ON Alcohol 190

6 **Proteins and Amino Acids** 203
7 **Energy Balance and Weight Management** 239

FOCUS ON Eating Disorders 284

8 **The Water-Soluble Vitamins** 303
9 **The Fat-Soluble Vitamins** 345

FOCUS ON Phytochemicals 376

10 **Water and the Electrolytes** 385
11 **Major Minerals and Bone Health** 413
12 **The Trace Minerals** 443

FOCUS ON Dietary Supplements 478

13 **Nutrition and Physical Activity** 491
14 **Nutrition During Pregnancy and Lactation** 535
15 **Nutrition from Infancy to Adolescence** 577
16 **Nutrition and Aging: The Adult Years** 607
17 **Food Safety** 635

FOCUS ON Biotechnology 670

18 **World Hunger and Malnutrition** 685

Appendices A-1

Glossary G-1

References R-1

Index I-1

Contents

1 Nutrition: Food for Health 3

Nutrition, Food Choices, and the American Diet 4

Why We Eat What We Eat 4

Food in 21st-Century America 6

How Healthy Is the American Diet? 6

Food Provides Nutrients 8

The Six Classes of Nutrients 9

What Nutrients Do 11

Nutrition and Health 12

How Undernutrition Affects Health 12

How Overnutrition Affects Health 13

How Our Diets Interact with Our Genetic Makeup 13

How to Choose a Healthy Diet 14

DEBATE Is There a "Best" Diet for You? 15

The Science Behind Nutrition 18

The Scientific Method 19

How Scientists Study Nutrition 20

SCIENCE APPLIED How Epidemiology Led to Dietary Recommendations for Heart Disease 22

CRITICAL THINKING Early Science 23

Ethical Concerns in Scientific Study 24

Evaluating Nutrition Information 25

Does It Make Sense? 26

What's the Source? 26

Is It Based on Good Science? 27

OFF THE LABEL Beware of Misleading Claims 28

Has It Stood the Test of Time? 29

Outcome 30

Summary 30

Mauritius Images/ Age Fotostock America, Inc.

2 Nutrition Guidelines: Applying the Science of Nutrition 33

The Development of Nutrition Recommendations 34

Early U.S. Dietary Recommendations 34

A Shift in the Focus of Dietary Guidance 35

DEBATE How Involved Should the Government Be in Your Food Choices? 36

Dietary Reference Intakes 37

Recommendations for Nutrient Intake 38

Recommendations for Energy Intake 39

Applications of the Dietary Reference Intakes 40

The Dietary Guidelines for Americans, 2015–2020 40

What Are the Dietary Guidelines? 40

Follow a Healthy Eating Pattern 41

Shift to Healthier Choices 43

Support from All Segments of Society 44

MyPlate: Putting the Dietary Guidelines into Practice 45

Understanding the MyPlate Messages 45

How to Use MyPlate 45

CRITICAL THINKING Fitting Foods, Meals, and Diets onto MyPlate 50

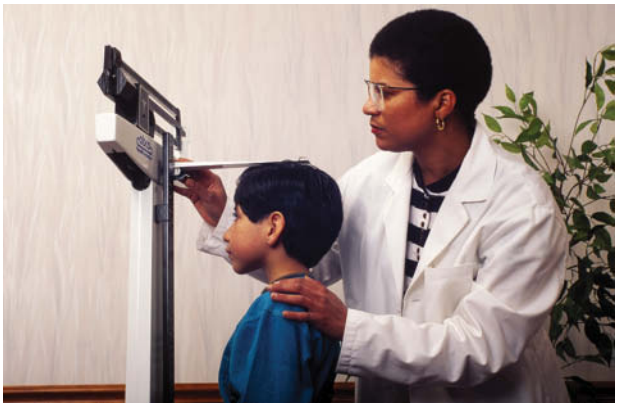
Food and Supplement Labels 51

Food Labels 52

OFF THE LABEL Using Food Labels to Choose Wisely 54
Dietary Supplement Labels 55
Understanding Label Claims 56
What Must Be Labeled? 58

Other Nutrition Guidelines 59
The Healthy People Initiative 60
Choice (Exchange) Lists for Meal Planning 60
Recommendations from Special Interest Groups 61

Assessing Nutritional Health 62
How to Assess an Individual's Nutritional Status 62
How the Nutritional Health of a Population Is Assessed 67
SCIENCE APPLIED NHANES: A Snapshot of America's Nutritional Health 68
Outcome 70
Summary 70



Blair Seitz/Photo Researchers

3 Digestion, Absorption, and Metabolism 73

Food Becomes Us 74
Atoms Form Molecules 74
Cells Form Tissues and Organs 74
Organs Cooperate as Organ Systems 74

The Digestive System 75
Organs of the Digestive System 76
Digestive Secretions 77
How Gastrointestinal Activity Is Regulated 78

Digestion and Absorption 78
The Mouth 79
The Pharynx 79
The Esophagus 80
The Stomach 80
The Small Intestine 83
The Large Intestine 86

The Gastrointestinal Tract and Health 87
The Intestinal Microbiota 87
Immune Function: How Our Gut Protects Us 88
DEBATE Should You Be Gluten Free? 90
Common Digestive Complaints 90
OFF THE LABEL Antacids: Learning the Drug Facts 93
SCIENCE APPLIED Discovering What Causes Ulcers 94
The Digestive System Throughout Life 96
CRITICAL THINKING How Gastrointestinal Problems Can Affect Nutrition 98

Delivering Nutrients to Body Cells 99
Why the Cardiovascular System Is Important in Nutrition 99
The Roles of the Lymphatic System 101
How Nutrients Enter Body Cells 101

Metabolism of Nutrients: An Overview 102
Anabolism and Catabolism 102
Producing ATP 103
Synthesizing New Molecules 104

Elimination of Metabolic Wastes 105
The Respiratory System and Skin 106
The Kidneys 106
Outcome 106
Summary 106

4 Carbohydrates: Sugars, Starches, and Fiber 109

Carbohydrates in Our Food 110
How Refined and Unrefined Carbohydrates Differ 111
DEBATE Should You Avoid High-Fructose Corn Syrup? 112

Why We Should Limit Added Sugars 112

Types of Carbohydrates 114

Simple Carbohydrates 114

Complex Carbohydrates 116

Carbohydrates in the Digestive Tract 118

Carbohydrate Digestion and Absorption 119

Lactose Intolerance 120

Fiber in the Digestive Tract 121

Carbohydrates in the Body 122

Carbohydrate Functions 123

Delivering Glucose to Body Cells 123

How Glucose Provides Energy 125

What Happens When Carbohydrate Is Limited? 126

Carbohydrates and Health 128

Diabetes Mellitus 128

SCIENCE **APPLIED** How the Discovery of Insulin Made Diabetes Treatable 132

Hypoglycemia 132

Dental Caries 133

Carbohydrates and Weight Management 134

Carbohydrates and Heart Disease 135

Fiber and Bowel Health 135

Fiber and Colon Cancer 136

Meeting Recommendations for Carbohydrate Intake 137

Carbohydrate Recommendations 137

Translating Recommendations into Healthy Diets 139

CRITICAL **THINKING** Becoming Less Refined 142

OFF THE LABEL What Does the Ingredient List Tell You about Carbohydrates? 144

The Role of Alternative Sweeteners 144

Outcome 147

Summary 148

Shaiith/iStock/Getty Images

5 **Lipids: Triglycerides, Phospholipids, and Cholesterol 151**

Fats in Our Food 152

Sources of Fat in Our Diet 152

How Dietary Fat Affects Health 153

Types of Lipids 154

Triglycerides and Fatty Acids 154

Phospholipids 158

Sterols 159

Lipids in the Digestive Tract 160

Lipid Transport in the Body 161

How Lipids Are Transported from the Small Intestine 162

How Lipids Are Transported from the Liver 162

SCIENCE **APPLIED** How a Genetic Disease Led to Treatment for High Blood Cholesterol 164

How Cholesterol Is Eliminated 165

Lipid Functions in the Body 165

Lipids Provide Structure and Lubrication 165

How Lipids Regulate Body Processes 166

How Triglycerides Provide Energy 167

How Fat Is Stored and Retrieved 167

Lipids and Health 170

Cardiovascular Disease 170

DEBATE Coconut Oil: Does a Tablespoon a Day Keep the Doctor Away? 176

Dietary Fat and Cancer 177
Dietary Fat and Obesity 178

Meeting Recommendations for Fat Intake 178
Fat and Cholesterol Recommendations 178
Translating Recommendations into Healthy Diets 181
CRITICAL THINKING Choosing Healthy Fats 183
OFF THE LABEL Making Sure Your Meat Is Lean 184
The Role of Reduced-Fat Foods and Fat Replacers 186
Outcome 188
Summary 188

FOCUS ON Alcohol 190

What's in Alcoholic Beverages? 191

Alcohol Absorption and Excretion 192

Alcohol Metabolism 193
Alcohol Dehydrogenase 193
Microsomal Ethanol-Oxidizing System 194

Adverse Effects of Alcohol Consumption 195
What Are the Acute Effects of Alcohol Consumption? 195
What Are the Chronic Effects of Alcohol Use? 196
What Defines Alcoholism? 198

Benefits of Moderate Alcohol Consumption 199

6 Proteins and Amino Acids 203

Protein in Our Food 204
Sources of Protein in Our Diet 204
How Protein Sources Impact the Overall Diet 204

Protein Molecules 205
Amino Acid Structure 205
Protein Structure 206

Protein in the Digestive Tract 208
Protein Digestion 208
Amino Acid Absorption 208
Why Undigested Protein Can Cause Food Allergies 209

Amino Acid Functions in the Body 210
Proteins Are Continually Broken Down and Resynthesized 210
How Amino Acids Are Used to Synthesize Proteins 211
SCIENCE APPLIED How Bacteria Created the Field of Biotechnology 212
Synthesis of Nonprotein Molecules 213
How Amino Acids Provide Energy 214

Functions of Body Proteins 215
How Proteins Provide Structure 215
How Proteins Facilitate and Regulate Body Processes 215

Protein, Amino Acids, and Health 218
Protein Deficiency 218
Protein Excess 220
DEBATE The Highs and Lows of High-Protein Diets 221
OFF THE LABEL Is It Safe for You? 222
Protein and Amino Acid Intolerances 223

Meeting Recommendations for Protein Intake 224
How Protein Requirements Are Determined 225
Protein Recommendations 226
Translating Recommendations into Healthy Diets 228

Vegetarian Diets 232
What Are the Benefits of Vegetarian Diets? 232
Why Some Nutrients Are at Risk of Deficiency in Vegetarian Diets 233
CRITICAL THINKING Choosing a Healthy Vegetarian Diet 234
How to Plan A Healthy Vegetarian Diet 235
Outcome 236
Summary 236

© Alison Wright/NG Images

7 Energy Balance and Weight Management 239

Body Weight and Health 240

Why Are We Getting Fatter? 241

How Excess Body Fat Affects Health 242

Health Implications of Being Underweight 244

Guidelines for a Healthy Body Weight 244

Body Mass Index 244

Body Composition 246

How Location of Body Fat Affects Health Risk 248

Exploring Energy Balance 250

Energy In: Calories Consumed in Food 250

OFF THE LABEL How Many Calories in That Bowl, Box, or Bottle? 252

Energy Out: Calories Used by the Body 253

Storing Energy and Using Energy Stores 256

Estimating Energy Requirements 258

How Energy Expenditure Is Measured 259

How to Calculate EER 259

What Determines Body Size and Shape? 262

Genes versus Environment 262

How Food Intake and Body Weight Are Regulated 263

Why Some People Gain Weight Easily 265

SCIENCE APPLIED Leptin: Discovery of an Obesity Gene 266

Weight Management 268

Who Would Benefit from Weight Loss? 268

Weight-Loss Goals 269

Why Maintaining Weight Loss Is Challenging 269

An Ideal Weight-Management Program 270

Managing America's Weight 272

Suggestions for Weight Gain 272

Approaches to Weight Loss 272

CRITICAL THINKING Balancing Energy: Genetics and Lifestyle 273

Methods to Reduce Energy Intake 273

© Frank Herholdt / Alamy

Weight-Loss Drugs and Supplements 277

Bariatric Surgery 278

DEBATE Is Surgery a Good Solution to Obesity? 279

Outcome 281

Summary 281

FOCUS ON Eating Disorders 284

What Are Eating Disorders? 285

What Causes Eating Disorders? 285

The Role of Genetics 286

Psychological Characteristics 286

Sociocultural Factors 286

Anorexia Nervosa 288

Psychological Issues 289

Behaviors Associated with Anorexia Nervosa 289

Physical Symptoms of Anorexia Nervosa 290

Treatment 290

Bulimia Nervosa 291

Psychological Issues 291

Behaviors Associated with Bulimia Nervosa 292

Physical Complications of Bulimia Nervosa 292

Treatment 293

Binge-Eating Disorder 293

Eating Disorders in Special Groups 294

Eating Disorders in Men 294

Eating Disorders During Pregnancy 296

Eating Disorders in Children 296

Eating Disorders in Athletes 297

Eating Disorders and Diabetes 298

Preventing and Getting Treatment for Eating Disorders 299
How to Recognize Those at Risk 299
How to Get Help for a Friend or Family Member 299
Reducing the Prevalence of Eating Disorders 301

8 The Water-Soluble Vitamins 303

What Are Vitamins? 304
Vitamins in Our Diet 304
DEBATE Super-Fortified Foods: Are They a Healthy Addition to Your Diet? 306
Absorption, Storage, and Excretion of Vitamins 307
What Vitamins Do 308
Meeting Vitamin Needs 309

Thiamin 311
Thiamin in the Diet 311
How Thiamin Functions in the Body 312
Thiamin Deficiency 312
Recommended Thiamin Intake 313
Thiamin Toxicity and Supplements 313

Riboflavin 314
Riboflavin in the Diet 314
How Riboflavin Functions in the Body 314
Riboflavin Deficiency 315
Recommended Riboflavin Intake 315
Riboflavin Toxicity and Supplements 315

Niacin 315
Niacin in the Diet 316
SCIENCE APPLIED Pellagra: Infectious Disease or Dietary Deficiency? 317
How Niacin Functions in the Body 318
Niacin Deficiency 318
Recommended Niacin Intake 318
Niacin Toxicity and Supplements 319

Biotin 319
Biotin in the Diet 319
How Biotin Functions in the Body 319
Biotin Deficiency 319

Kostiantyn Ablazov / Shutterstock

Recommended Biotin Intake 320
Biotin Toxicity 320

Pantothenic Acid 320
Pantothenic Acid in the Diet 320
How Pantothenic Acid Functions in the Body 320
Pantothenic Acid Deficiency 320
Recommended Pantothenic Acid Intake 320
Pantothenic Acid Toxicity 321

Vitamin B_6 321
Vitamin B_6 in the Diet 321
How Vitamin B_6 Functions in the Body 322
Vitamin B_6 Deficiency 322
How Vitamin B_6 Status Is Related to Cardiovascular Disease 324
Recommended Vitamin B_6 Intake 324
Vitamin B_6 Toxicity and Supplements 324

Folate (Folic Acid) 325
Folate in the Diet and the Digestive Tract 326
How Folate Functions in the Body 327
Folate Deficiency 327
Recommended Folate Intake 329
Meeting Folate Needs 329
CRITICAL THINKING Meeting Folate Recommendations 330
Folate Toxicity 331

Vitamin B_{12} 331
Vitamin B_{12} in the Diet 331

Vitamin B_{12} in the Digestive Tract 332
How Vitamin B_{12} Functions in the Body 333
Vitamin B_{12} Deficiency 333
Recommended Vitamin B_{12} Intake 334
Vitamin B_{12} Toxicity and Supplements 334

Vitamin C 335
Vitamin C in the Diet 335
How Vitamin C Functions in the Body 336
Vitamin C Deficiency 337
Recommended Vitamin C Intake 337
Vitamin C Toxicity and Supplements 338

Choline and Other Vitamin-Like Compounds 339
Outcome 341
Summary 342

9 The Fat-Soluble Vitamins 345

Fat-Soluble Vitamins in Our Diet 346

Vitamin A Sources and Functions 346
Vitamin A in the Diet 347
Vitamin A in the Digestive Tract 348
How Vitamin A Functions in the Body 348

Meeting Vitamin A Needs 351
Vitamin A Deficiency 351
DEBATE Combating Vitamin A Deficiency with Golden Rice 352
CRITICAL THINKING How Much Vitamin A Is in Your Fast-Food Meal? 353
Recommended Vitamin A Intake 355
Vitamin A Toxicity and Supplements 356

Vitamin D 357
Vitamin D in the Diet 357
How Vitamin D Functions in the Body 357
Vitamin D Deficiency 360
Recommended Vitamin D Intake 361
Meeting Vitamin D Needs 362
Vitamin D Toxicity 362

Vitamin E 363
Vitamin E in the Diet 363

Erik De Castro/Reuters/Newscom

How Vitamin E Functions in the Body 364
Vitamin E Deficiency 365
Recommended Vitamin E Intake 366
Vitamin E Toxicity and Supplements 366

Vitamin K 366
Vitamin K in the Diet 366
How Vitamin K Functions in the Body 367
Vitamin K Deficiency 367
Recommended Vitamin K Intake 368
Vitamin K Toxicity and Supplements 368
SCIENCE APPLIED Saving Cows, Killing Rats, and Surviving Heart Attacks 369

Vitamin/Mineral Supplements 370
Who Needs Vitamin/Mineral Supplements? 371
Choose Supplements with Care 371
OFF THE LABEL Read the Label Before You Supplement 372
Outcome 373
Summary 374

FOCUS ON Phytochemicals 376

Phytochemicals in Our Food 377
Carotenoids 378
Flavonoids 379
Indoles, Isothiocyanates, and Alliums 379
Phytoestrogens 380

How to Choose a Phytochemical-Rich Diet 381
Eat More Fruits and Vegetables 381
Make Half Your Grains Whole 382
Choose Plant Proteins 382
Added versus Naturally Occurring Phytochemicals 383

10 Water and the Electrolytes 385

Water: The Internal Sea 386

How Water Functions in the Body 386

How Water Is Distributed Throughout the Body 387

Water Balance 389

Water Intake 390

Water Losses 391

Water Deficiency: Dehydration 392

Water Intoxication: Overhydration 393

Recommended Water Intake 394

DEBATE Is Bottled Water Better? 395

Electrolytes: Salts of the Internal Sea 396

Sodium, Potassium, and Chloride in Our Food 396

How Sodium, Potassium, and Chloride Function in the Body 397

How Electrolyte Balance Is Regulated 398

Electrolyte Deficiency 399

Electrolyte Toxicity 400

Hypertension 401

What Causes Hypertension? 402

Factors That Affect the Risk of Hypertension 402

How Diet Affects Blood Pressure 402

Healthy Electrolyte Intakes 403

SCIENCE APPLIED A DASH to Heart Health 404

Recommended Sodium, Chloride, and Potassium Intakes 404

Choosing a Dietary Pattern to Lower Blood Pressure 406

CRITICAL THINKING DASHing a Diet 408

OFF THE LABEL Look for Less Sodium and More Potassium 409

Outcome 410

Summary 411

11 Major Minerals and Bone Health 413

What Are Minerals? 414

Minerals in Our Diet 414

Understanding Mineral Needs 416

Minerals, Osteoporosis, and Bone Health 418

Bone Structure, Formation, and Breakdown 418

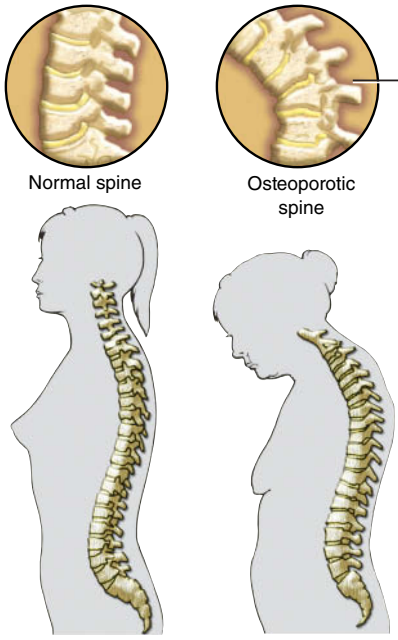
Osteoporosis 420

SCIENCE APPLIED Bone: Lost in Space 423

How to Prevent and Treat Osteoporosis 424

CRITICAL THINKING Osteoporosis Risk 425

DEBATE Are Supplements a Safe Way to Meet Your Calcium Needs? 426



Larry Mulvehill/Photo Researchers, Inc.

Calcium (Ca) 427

Calcium in the Diet 427

Calcium in the Digestive Tract 428

How Calcium Functions in the Body 429

Calcium Deficiency 430

Recommended Calcium Intake 430

Meeting Calcium Needs 431

OFF THE LABEL How Much Calcium Is in Your Yogurt? 432

Excessive Calcium 433

Phosphorus (P) 434
Phosphorus in the Diet 434
Phosphorus in the Digestive Tract 435
How Phosphorus Functions in the Body 435
Phosphorus Deficiency 435
Recommended Phosphorus Intake 436
Excessive Phosphorus 436

Magnesium (Mg) 436
Magnesium in the Diet 436
Magnesium in the Digestive Tract 436
How Magnesium Functions in the Body 437
Magnesium Deficiency 437
Recommended Magnesium Intake 438
Magnesium Toxicity and Supplements 438

Sulfur (S) 438
Outcome 439
Summary 440

12 **The Trace Minerals** 443

Trace Minerals in Our Diet 444

Iron (Fe) Sources and Functions 444
Iron in the Diet 444
Iron in the Digestive Tract 445
How Iron Homeostasis Is Regulated 446
How Iron Functions in the Body 448

Meeting Iron Needs 448
Iron Deficiency 448
Recommended Iron Intake 450
Iron Toxicity 450
CRITICAL THINKING Increasing Iron Intake and Uptake 452
How to Get Enough Iron 453

Zinc (Zn) 454
Zinc in the Diet 454
Zinc in the Digestive Tract 454
How Zinc Functions in the Body 455
Zinc Deficiency 457

Keith Weller/Courtesy USDA

Recommended Zinc Intake 457
Zinc Toxicity 457
Zinc Supplements 457

Copper (Cu) 458
Copper in the Diet 458
Copper in the Digestive Tract 459
How Copper Functions in the Body 459
Copper Deficiency 460
Recommended Copper Intake 460
Copper Toxicity 460

Manganese (Mn) 460
How Manganese Functions in the Body 460
Manganese Deficiency and Toxicity 460
Recommended Manganese Intake 461

Selenium (Se) 461
Selenium in the Diet 461
How Selenium Functions in the Body 462
Selenium Deficiency 462
Recommended Selenium Intake 463
Selenium Toxicity and Supplements 463
DEBATE Antioxidant Supplements: Helpful or Harmful? 464

Iodine (I) 464
Iodine in the Diet 465
How Iodine Functions in the Body 465
Iodine Deficiency 466
OFF THE LABEL Should You Choose Salt Labeled "Iodized"? 468
Recommended Iodine Intake 468
Iodine Toxicity 468

Chromium (Cr) 469
Chromium in the Diet 469
How Chromium Functions in the Body 469
Chromium Deficiency 469
Recommended Chromium Intake 470
Chromium Supplements and Toxicity 470

Fluoride (F) 470
Fluoride in the Diet 470
SCIENCE **APPLIED** How "Colorado Brown Stain" Led to "Look, Mom! No Cavities!" 471
How Fluoride Functions in the Body 472
Fluoride Deficiency 472
Recommended Fluoride Intake 472
Fluoride Toxicity 472

Molybdenum (Mo) 473

Other Trace Elements 475
Outcome 475
Summary 476

FOCUS ON Dietary Supplements 478

What Is a Dietary Supplement? 479
Dietary Supplement Labels 479
Regulation of Dietary Supplements 479

Nutrient Supplements 481
Vitamins and Minerals 481
Supplemental Carbohydrate 481
Protein and Amino Acid Supplements 482
Supplements of Omega-3 Fatty Acids 482

Substances Made in the Body 482
Enzyme Supplements 483
Hormone Supplements 483
Coenzyme Supplements 484
Supplements Containing Structural and Regulatory Molecules 484

Phytochemical Supplements 485
Carotenoids 485
Flavonoids 485

Herbal Supplements 486
Ginkgo Biloba 486
St. John's Wort 487
Ginseng 487
Garlic 487
Echinacea 489
Saw Palmetto 489
Kava 489

13 Nutrition and Physical Activity 491

Nutrition, Physical Activity, and Health 492
How Physical Activity Improves Fitness 492
How Physical Activity Benefits Health 495

Physical Activity Recommendations 497
What to Look for in a Fitness Program 497
Physical Activity Recommendations for Children 500
How to Create an Active Lifestyle 500

Exercise and Energy Metabolism 502
How Exercise Duration Affects Metabolism 502
How Exercise Intensity Affects Metabolism 506
Why Training Increases Aerobic Capacity 507

Energy and Nutrient Needs for Physical Activity 508
Energy Needs 509
Carbohydrate, Fat, and Protein Needs 511
Vitamin and Mineral Needs 512
CRITICAL **THINKING** Getting Enough Protein 513

Fluid Needs for Physical Activity 515
How Dehydration Affects Health and Performance 515
Why Heat-Related Illness Is a Concern for Athletes 516
Causes and Consequences of Hyponatremia 517
Recommended Fluid Intake for Exercise 517
DEBATE Energy Drinks for Athletic Performance? 519

Food and Drink to Maximize Performance 520
Maximizing Glycogen Stores 520
What to Eat Before Exercise 520
What to Eat During Exercise 521
What to Eat After Exercise 521

RW Photographic/Masterfile

OFF THE LABEL What Are You Getting from That Sports Bar? 522

Ergogenic Aids: Do Supplements Enhance Athletic Performance? 523

Vitamin and Mineral Supplements 523

Supplements to Build Muscle 525

Supplements to Enhance Performance in Short, Intense Activities 527

SCIENCE APPLIED EPO: Lifesaver and Scandal 528

Supplements to Enhance Endurance 529

How Diet and Supplements Affect Performance 531

Outcome 531

Summary 531

14 Nutrition During Pregnancy and Lactation 535

The Physiology of Pregnancy 536

Prenatal Growth and Development 536

What Changes Occur in the Mother? 538

Discomforts of Pregnancy 540

Complications of Pregnancy 541

The Nutritional Needs of Pregnancy 543

Energy Needs During Pregnancy 543

Protein, Carbohydrate, and Fat Recommendations 544

Water and Electrolyte Needs 545

Micronutrient Needs During Pregnancy 545

SCIENCE APPLIED Folate: Reducing Birth Defects through Fortification 547

Meeting Nutrient Needs with Food and Supplements 548

CRITICAL THINKING Nutrient Needs for a Successful Pregnancy 550

Factors That Increase the Risks of Pregnancy 552

Maternal Nutritional Status 553

Maternal Health Status 554

Socioeconomic Factors 555

Exposure to Toxic Substances 555

Lactation 559

Milk Production and Letdown 559

How Lactation Affects Maternal Nutrient Needs 560

The Nutritional Needs of Infancy 562

Energy Needs During Infancy 563

Fat Recommendations 564

Carbohydrate Intake 564

Protein Requirements 564

Water Needs 564

DEBATE DHA-Fortified Infant Formulas 565

Micronutrient Needs of Infants 566

Infant Growth and Nutritional Status 566

Feeding the Newborn 568

Meeting Nutrient Needs with Breast-Feeding 568

Meeting Nutrient Needs with Bottle-Feeding 571

Outcome 573

Summary 574

Sarah Leen/NG Image Collection

15 Nutrition from Infancy to Adolescence 577

Starting Right for a Healthy Life 578

What Are American Children Eating? 578

How Poor Food Choices Are Impacting Children's Health 579
Healthy Eating Is Learned for Life 580

Nourishing Infants, Toddlers, and Children 580
Monitoring Growth 581
Nutrient Needs of Infants and Children 582
Meeting Infants' and Children's Nutrient Needs 583
SCIENCE APPLIED Vitamin D: From Cod Liver Oil to Fortified Milk 584

Nutrition and Health Concerns in Infants and Children 590
Food Allergies and Intolerances 590
Dental Caries 591
Diet and Attention Deficit/Hyperactivity Disorder 591
Lead Toxicity 592
Childhood Obesity 592
CRITICAL THINKING Undernutrition May Accompany Overnutrition 593

Adolescents 596
The Changing Body: Sexual Maturation 597
Nutrient Needs of Adolescents 597
DEBATE Will Banning Soda from Schools Reduce Obesity? 599
Meeting Adolescents' Nutrient Needs 600

Special Concerns of Teenagers 601
How Vegetarian Diets Affect Nutritional Health 601
Eating for Appearance and Performance 602
Oral Contraceptive Use 603
Teenage Pregnancy 603
Tobacco Use 604
Alcohol Use 604
Outcome 604
Summary 605

16 Nutrition and Aging: The Adult Years 607

What Is Aging? 608
SCIENCE APPLIED Eat Less—Live Longer? 608
How Long Can Americans Expect to Live? 609
How Long Can Americans Expect to Be Healthy? 610

What Causes Aging? 611
Programmed Cell Death 611
Wear and Tear 611
How Genetics, Environment, and Lifestyle Interact 611

Aging and the Risk of Malnutrition 612
How Physiological Changes Affect the Risk of Malnutrition 613
Why Medical Conditions Contribute to Malnutrition 617
How Economic, Social, and Psychological Factors Affect Nutritional Status 620

Photo and Co/Getty Images, Inc.

Nutritional Needs and Concerns of Older Adults 621
Energy and Macronutrient Needs 621
Micronutrient Needs 622

Keeping Older Adults Healthy 624
Maintaining a Healthy Weight 625
How to Plan a Healthy Diet for Older Adults 625
DEBATE Are Herbal Supplements Helpful or Harmful? 627
Physical Activity for Older Adults 628
How to Prevent Food Insecurity 629
CRITICAL THINKING Averting Malnutrition 631
Nutrition Programs for the Elderly 631
Outcome 632
Summary 633

17 Food Safety 635

How Can Food Make Us Sick? 636
What Is Food-Borne Illness? 636
How Does Food Get Contaminated? 636
When Do Contaminants Make Us Sick? 636

Keeping Food Safe 638
What Is the Government's Role? 638
What Is the Role of Food Manufacturers and Retailers? 640
What Is the Consumer's Role? 642

Pathogens in Food 642
Bacteria 644
Viruses 646
Molds 648
Parasites 649
Prions 649

How to Reduce the Risk of Microbial Food-Borne Illness 650
Store Food Properly 651
Handle Food Safely 651
Cook Food Thoroughly 652
Food Safety Away from Home 653

Agricultural and Industrial Chemicals in Food 653
CRITICAL THINKING Safe Picnic Choices 654
Risks and Benefits of Pesticides 654
Antibiotics and Hormones in Food 657
DEBATE Should You Go Organic? 658
Contamination from Industrial Wastes 658
How to Choose Wisely to Minimize Agricultural and Industrial Contaminants 659

Technology for Keeping Food Safe 660
How Temperature Keeps Food Safe 661
SCIENCE APPLIED Pasteurization: From Spoiled Wine to Safe Milk 662
How Irradiation Preserves and Protects Food 663
How Packaging Protects Food 664
Food Additives 665
OFF THE LABEL Are All Food Additives Safe for You? 667
Outcome 668
Summary 669

FOCUS ON Biotechnology 670

How Does Biotechnology Work? 671
Genetics: From Genes to Traits 671
Methods of Biotechnology 673
Is Genetic Modification Really New? 675

Applications of Modern Biotechnology 676
How Biotechnology Can Increase Crop Yields 677
How Biotechnology Can Improve Nutritional Quality 678
How Biotechnology Impacts Food Quality and Processing 678
How Biotechnology Is Used in Animal Food Production 678
How Biotechnology Is Used to Combat Disease 679

Safety and Regulation of Genetically Modified Foods 679
Consumer Safety 680
Environmental Concerns 681
Regulation of Genetically Engineered Food Products 682

18 World Hunger and Malnutrition 685

The Two Faces of Malnutrition 686
The Impact of Undernutrition 686
Overnutrition: A World Health Problem 688
Why Undernutrition and Overnutrition Exist Side by Side 688

Causes of Hunger and Undernutrition 689
Food Shortages 689
DEBATE Are Vegetarian Diets Better for People and for the Environment? 692
Poor-Quality Diets 693
SCIENCE APPLIED Vitamin A: The Anti-Infective Vitamin 696

© AP/Wide World Photos

Eliminating World Hunger 697
Providing Short-Term Food Aid 697
Eliminating Poverty 697
Providing Enough Food 698
Ensuring a Nutritious Food Supply 700
CRITICAL **THINKING** Can You Have an Impact? 701
Providing Education 702
Hunger at Home 703
Causes of Food Insecurity 703
Federal Programs to Prevent Malnutrition 707
Outcome 708
Summary 708

A. Additional DRI Tables A-1
B. Other Government Recommendations A-2
C. U.S. Nutrition Recommendations and Guidelines A-5
D. Energy Expenditure for Various Activities A-7
Glossary G-1
References R-1
Index I-1

NUTRITION

SCIENCE AND APPLICATIONS

4th EDITION

WILEY

CHAPTER OUTLINE

1.1 Nutrition, Food Choices, and the American Diet
Why We Eat What We Eat
Food in 21st-Century America
How Healthy Is the American Diet?

1.2 Food Provides Nutrients
The Six Classes of Nutrients
What Nutrients Do

1.3 Nutrition and Health
How Undernutrition Affects Health
How Overnutrition Affects Health
How Our Diets Interact with Our Genetic Makeup
How to Choose a Healthy Diet

1.4 The Science Behind Nutrition
The Scientific Method
How Scientists Study Nutrition
Ethical Concerns in Scientific Study

1.5 Evaluating Nutrition Information
Does It Make Sense?
What's the Source?
Is It Based on Good Science?
Has It Stood the Test of Time?

(©iStockphoto)

Mauritius Images/Age Fotostock America, Inc.

Nutrition: Food for Health

1

CASE STUDY

Kaitlyn peered into the minifridge in her dorm room looking for something to eat. The only thing she had was some leftover pizza and a couple of cookies. Kaitlyn had been in classes and then at work until late in the evening, so when she finally sat down to study, she realized that she had completely forgotten to eat dinner. She needed to eat something to keep her going until she finished that chapter in her nutrition book, but her dorm offered few food choices late at night. After finishing the pizza, Kaitlyn headed down the hall to get a bag of potato chips and an energy drink from the vending machine. She knew that they weren't a good choice, but they were her only option.

As a college freshman away from home for the first time, Kaitlyn has gained a few pounds and is beginning to be concerned about her weight. Her father recently suffered heart problems, and her mother takes medication for high blood pressure. Kaitlyn knows that because of this family history, her diet is particularly important for her future health. Though the dorm cafeteria offers a variety of choices, Kaitlyn never learned how to choose a healthy diet. She wants to keep healthy foods in her refrigerator, but never takes time to go to the store.

Several of Kaitlyn's friends have started taking supplements like Mega B to give them more energy and ginkgo biloba to improve their memories. She is tempted to start taking them but she's not sure the claims about them are true. **To optimize her health, Kaitlyn needs to learn the basics of nutrition science and perfect the art of making nutritionally sound decisions and healthy food choices—a goal that is a little overwhelming at first.**

© Alejandro Rivera/iStockphoto

1.1 Nutrition, Food Choices, and the American Diet

LEARNING OBJECTIVES

- Identify factors that affect our food choices.
- Describe two ways in which our food and eating patterns have changed during the past 50 years.
- Name two foods or nutrients that Americans over- or underconsume.

nutrition A science that studies the interactions between living organisms and food.

nutrients Substances in foods that provide energy and structure and help regulate body processes.

Nutrition is a science that studies all the interactions that occur between living organisms and food. Food provides **nutrients** and energy, which are needed to keep us alive and healthy, to support growth, and to allow reproduction. Which foods we choose determine the nutrients we get, which in turn affects how healthy we are. Many factors affect our food choices, and despite an abundant food supply Americans today don't always choose the right combination of foods to optimize nutritional health.

Why We Eat What We Eat

Our food choices are affected by more than our nutrient needs. We choose what we eat based on what is available to us, what we have learned to eat from our family and cultural traditions, what foods appeal to us for emotional reasons, and what our personal preferences are, whether based on what we enjoy or what we think we should eat.

food environment The physical, economic, and social factors that affect eating habits and patterns.

Availability The food available to an individual or a population is affected by the **food environment**, which includes factors such as access to grocery stores and restaurants, the products available in these stores and restaurants, food pricing, and food advertising. Economic status and health also affect what foods are available.

In developing parts of the world, dietary choices are often limited to foods produced locally. Nutrients that are lacking in local foods will be lacking in the population's diet. This is less of a factor in more-developed countries because the ability to store, transport, and process food allows year-round access to seasonal foods and foods grown and produced at distant locations (Figure 1.1).

iStock/Getty Images

FIGURE 1.1 Food from around the word
In the United States, seasonal fruits and vegetables are available all year long because they can be stored and shipped from around the globe.

Even if foods are available in the store, it doesn't mean that they are available to all individuals. Socioeconomic factors such as income level, living conditions, and education affect the types and amounts of foods to which people have access. Individuals with limited incomes can choose only the types and amounts of foods that they can afford. Individuals who don't own cars can purchase only what they can carry home. Those without refrigerators or stoves are limited in what foods can be prepared at home. And those who can't or don't have time to cook are limited to raw foods, prepared foods, and restaurant meals.

Health status also affects the availability of food. People who cannot carry heavy packages are limited in what they can purchase. People with food allergies, digestive problems, and dental disease are limited in the foods that are safe and comfortable for them to eat. People consuming special diets to manage disease conditions are limited to foods that meet their dietary prescriptions.

AFP/Getty Images

FIGURE 1.2 Culture dictates food acceptability If you grew up in Asia or Africa, you might consider grasshoppers, termites, or the silkworms in this Vietnamese market to be an acceptable food choice. Most Americans would not be willing to include insects as part of a meal.

Social and Cultural Considerations Food preferences and eating habits are learned as part of each individual's family, cultural, national, and social background (Figure 1.2). They are among the oldest and most entrenched features of every culture. In Japan rice is the focus of the meal, whereas in Italy, pasta is included with every meal. Curries characterize Indian cuisine, and we expect refried beans and tortillas when we go out for Mexican food.

Social, religious, and cultural traditions also affect what foods we choose. Each of us associates holidays such as Christmas, Easter, Passover, New Year's Day, and Kwanzaa with specific foods that are traditional in our family, religion, and culture. Seventh-Day Adventists espouse vegetarianism; Jews and Muslims do not eat pork; Sikhs and Hindus do not eat beef.

In addition to being part of our cultural heritage, food is the centerpiece of our everyday social interactions. We get together with friends for a meal or for a cup of coffee and dessert. The dinner table is often the focal point for communication within the family—a place where the experiences of the day are shared. Social events dictate our food choices in a number of ways. When invited to a friend's house for dinner, we may eat foods we don't like out of politeness to our hosts. We also sometimes alter our food choices because of peer pressure (Figure 1.3).

Psychological and Emotional Factors Food represents comfort, love, and security. Comfort foods such as hot tea and chicken soup help us to feel better when we are sick, sad, tired, or lonely. We use food as a reward when we are good—A's on a report card are celebrated with an ice cream cone. We sometimes take away food as punishment—a child who misbehaves is sent to bed without dessert. We celebrate milestones and reward life's accomplishments with food. Food may also be an expression and a moderator of mood and emotional states. When we are upset, some of us turn to chocolate or overeat in general, while others eat less or stop eating altogether.

Blend Images/Moxie Productions/Getty Images

FIGURE 1.3 Peer pressure affects food intake For an adolescent, having pizza after school may be an important part of being accepted by his or her peers.

Personal Preference We eat what we like. Tradition, religion, and social values may dictate what foods we consider appropriate, but personal preferences for taste, smell, appearance, and texture affect which foods we actually consume. How would you feel about giving up your favorite foods? Probably not too good, and you are not alone. Even though most Americans understand that nutrition is important to their health, many do not choose a healthy diet because they don't want to give up their favorite foods and they don't want to eat foods they don't like.[1] Personal convictions also affect food choices; a vegetarian would not choose a

meal that contains meat, and a person concerned about the environment may not buy foods packaged in nonrecyclable containers.

Individuals' perceptions about food and health also affect their food and nutrition choices. Some people may choose low-carbohydrate foods because they think these choices will help them lose weight. Others may limit red meat intake to reduce their risk of heart disease, or may purchase organically produced foods if they believe that reducing pesticide exposure will prevent illness.

Food in 21st-Century America

food processing The practices used by the food industry to transform raw plant and animal materials, such as grains, produce, meat, and milk, into products for consumers. Nearly all our food has been processed in some way.

For much of human history, people needed to spend most of their day obtaining food and preparing meals in order to get enough to eat. Even a generation ago, the time spent for meal preparation was measured in hours—hours spent peeling, chopping, baking, roasting, stewing, and then cleaning. Today, our homes are stocked with an endless assortment of foods available at a moment's notice. Many of these choices are foods that have been part of the human diet for centuries—fresh fruits and vegetables, milk, breads, and cereals. But others are newer additions created through **food processing**: frozen vegetables complete with sauce, dried soups and noodle bowls, pre-cooked packaged meats, frozen prepared meals, and an endless array of sweet and savory snack foods.

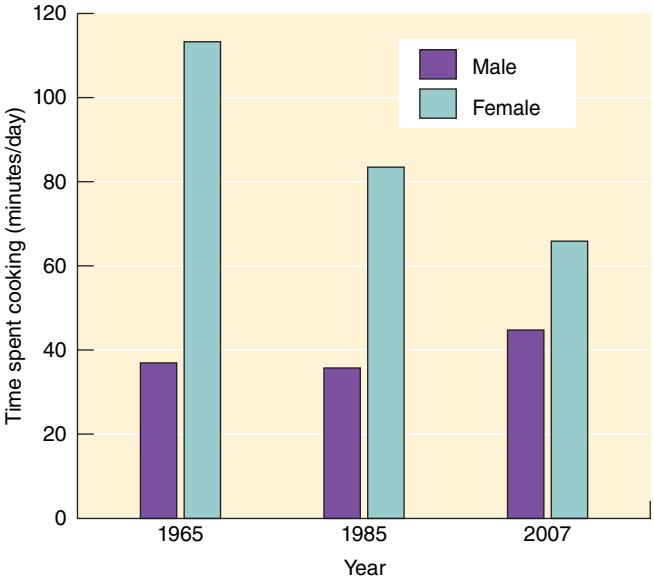


FIGURE 1.4 Time spent cooking
Since the 1960s the amount of time women spend cooking has decreased significantly. Due to other social changes, the amount of time men spend cooking has increased slightly.[2]

In addition to our food choices, our eating patterns have changed. Fifty years ago people ate most of their meals at home, with their families, at a leisurely pace. Today, more single-parent households and families with both parents working mean no one is home in the afternoon to prepare an evening meal. Dinner is a rush because busy after-school schedules impinge on family mealtimes. Fewer people today even know how to prepare a full meal, so shoppers of all ages are choosing to buy more convenient, processed foods that can be boiled or heated in the microwave rather than raw ingredients that need to be chopped, seasoned, and cooked (Figure 1.4).[2] These convenience foods have expanded our choices for meals at home and Americans are replacing more and more home-cooked meals with take-out food and meals eaten away from home. These meals tend to be higher in calories than foods prepared at home; almost a third of our calories currently come from meals eaten away from home.[3]

These changes in our food environment have made it easier and faster to obtain a meal or snack on the run, but the foods we choose are lower in whole grains, milk, fruits, and vegetables and higher in unhealthy saturated fat than the choices we make at home (Figure 1.5).[4] Over the past century, the major nutrition concerns in the United States have shifted from providing enough nutrients to meet people's needs to limiting overconsumption and reducing the incidence of chronic diseases related to excesses of energy and certain nutrients.

How Healthy Is the American Diet?

The American diet isn't as healthy as it could be. As it has become easier to obtain and prepare food, the amount of food we eat has increased. American adults eat more calories than they did 50 years ago primarily due to larger portion sizes, especially from fast foods, and an increase in the frequency of snacking and calories consumed from those snacks.[5,6] As a result, over two-thirds of American adults weigh more than they should.[7]

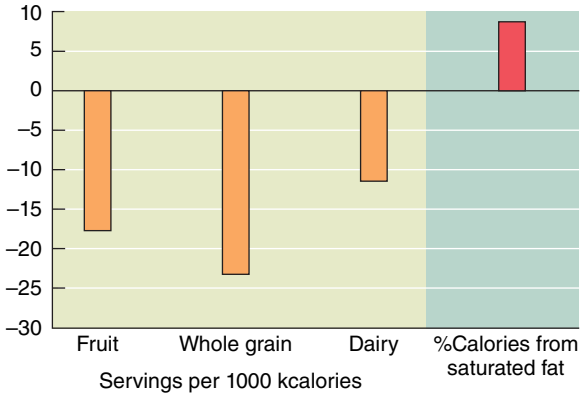
In addition to eating more calories than we need, we are not eating enough of the foods that make up a healthy diet. Recommendations suggest a diet based on whole grains, vegetables, and

Breakfast at home
A cup of coffee with whole milk and sugar and a cup of whole grain cereal with low-fat milk and a half a banana would cost about $1.00 and provide about 350 kcalories.

P. Langen/Getty Images

Breakfast out
A 16-ounce caramel mocha and a blueberry muffin at Dunkin' Donuts or the corner coffee bar would cost about $4 and provide about 770 kcalories.

P. Mittongtare/FoodPix/Getty Images



Dietary impact of eating breakfast away from home

On average, breakfast away from home decreases the number of servings of whole grains, fruit, and dairy consumed per 1000 kcalories and increases the percentage of calories from saturated fat.[4]

FIGURE 1.5 The costs of convenience
If you stop for a muffin and coffee on your way to work or school, you can save a couple of minutes, but you may pay a higher price than you think in terms of both dollars and nutrient intake. The impact of stopping for coffee and a muffin once in a while when you are running late is minimal, but making this an everyday habit can break your dollar and calorie budget and affect the quality of your overall diet.

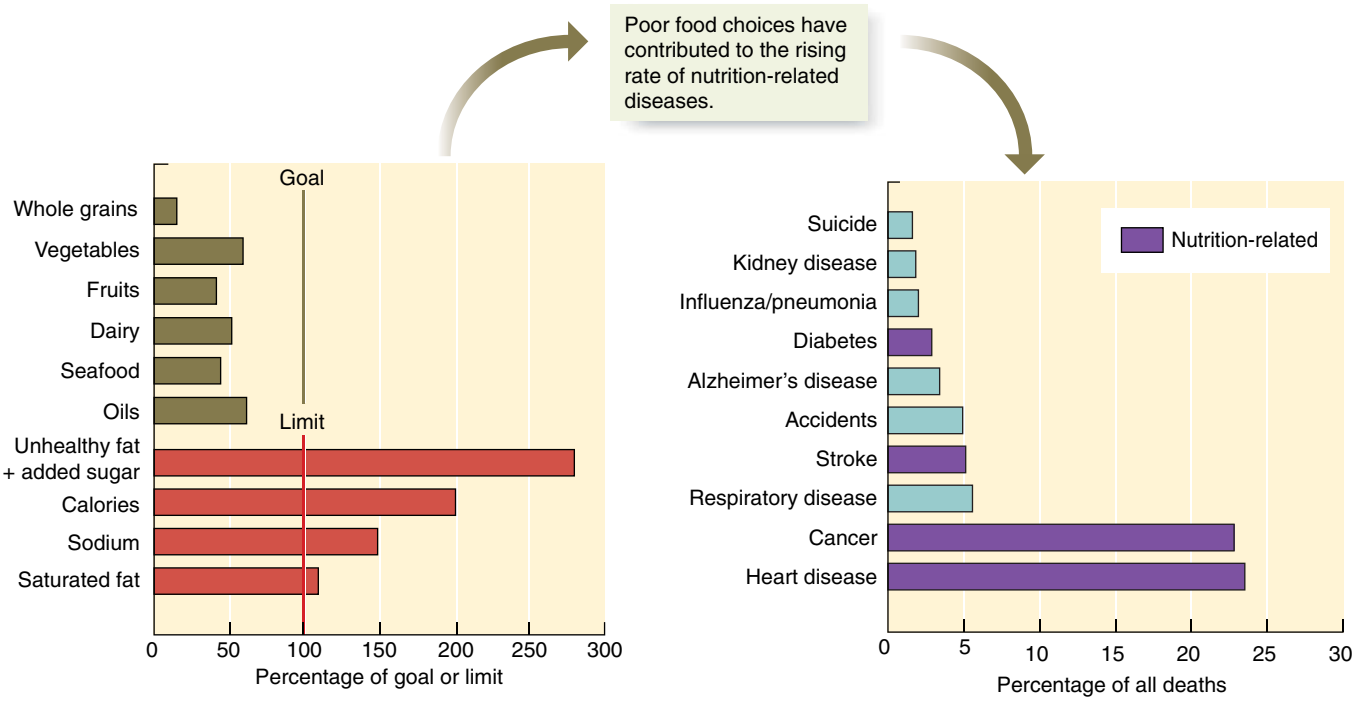
THINK CRITICALLY

iProfile Use iProfile to plan a 500-kcal lunch that you can prepare at home. How does the amount of food compare with 500 kcalories of food from a typical fast-food restaurant?

fruits, with smaller amounts of low-fat dairy products and lean meats and limited amounts of sweets and certain types of fats, such as saturated fat.[5] As a population, we don't eat enough whole grains, vegetables, fruits, seafood, or dairy products. We frequently choose French fries for a vegetable and consume few nutrient-rich dark green and deep yellow vegetables. Our diets are high in snack foods and desserts that supply us with more salt (sodium) and sugar than is recommended (Figure 1.6A).[5] Instead of milk, we are choosing sweetened beverages, especially carbonated soft drinks and fruit drinks.[8] This dietary pattern, along with a lack of physical activity, increases the risk of developing chronic diseases such as diabetes, obesity, heart disease, and cancer, which are the most common, costly, and preventable of all health problems in the United States (Figure 1.6B).[9–11] Recommendations for reducing disease risk focus on changes in the foods we choose and the amount of exercise we get.[5,12]

A healthy diet does not need to exclude processed convenience foods, but it must involve wise choices. To choose a healthy diet that provides the right amounts of energy and each nutrient, we need to understand how our bodies obtain nutrients from food, which nutrients are essential, how much we need, and which foods provide healthy sources of nutrients. We also need to recognize which nutrition information to believe.

FIGURE 1.6 Our current diet increases our health risks



A. The current U.S. dietary pattern is not as healthy as it could be. The graph shows the usual U.S. intake of selected foods and nutrients as a percentage of the recommended goal or limit.

B. The graph shows the leading causes of death in the United States; those shown in purple are nutrition related.[9]

1.2 Food Provides Nutrients

LEARNING OBJECTIVES

- Define the term *essential nutrient* and list the six classes of nutrients.
- Describe the three general functions of nutrients.
- Discuss how nutrition can affect your health in the short term and in the long term.

essential nutrient A nutrient that must be provided in the diet because the body either cannot make it or cannot make it in sufficient quantities to satisfy its needs.

fortified food Food to which one or more nutrients have been added.

enriched grains Grain products to which specific amounts of thiamin, riboflavin, niacin, and iron have been added. Since 1998 folic acid has also been added to enriched grains.

dietary supplement A product intended for ingestion in the diet that contains one or more of the following: vitamins, minerals, plant-derived substances, amino acids, and concentrates or extracts.

To date, approximately 45 nutrients have been determined to be essential to human life. **Essential nutrients** must be supplied in the diet to support life; they either cannot be made by the body or cannot be made in large enough quantities to meet needs. For example, our bodies cannot synthesize vitamin C, but we need it to stay healthy. If we do not consume vitamin C in the foods we eat, we will begin to show signs of a vitamin C deficiency. If vitamin C is not added back into the diet, the vitamin C deficiency will eventually be fatal.

Our intake of essential nutrients is determined by our food choices. Some foods are naturally high in nutrients, and some contain nutrients added during processing. Foods to which nutrients have been added are called **fortified foods**. Some fortified foods, such as milk with added vitamin A and **enriched grains**, have been a part of our food supply for decades. The government mandated the fortification of these foods to eliminate nutrient deficiencies in the population, and the amounts and types of nutrients added are specified. Other foods, such as orange juice with added calcium and flavored water with added vitamins and minerals, are not part of mandated fortification programs. These foods are fortified with nutrients to increase sales by meeting consumer demand for nutrient-rich foods. The amounts and types of nutrients added to these foods are at the discretion of the manufacturer. **Dietary supplements** are another source of nutrients in the American food supply. National surveys indicate that 68% of adults in the United States take dietary supplements, and vitamin and mineral supplements are the most popular category.[13]

In addition to nutrients, food contains substances that are needed by the body but are not essential in the diet. Lecithin, for example, is a substance found in egg yolks that is needed for nerve function. It is not considered an essential nutrient because it can be manufactured in the body in adequate amounts. The diet also contains substances that are not made by the body and are not necessary for life, but that have health-promoting properties. Those that come from plants are called **phytochemicals**; those that come from animal foods are called *zoochemicals*. For example, a phytochemical found in broccoli called sulforaphane is not essential in the diet but has effects in the body that may help reduce the risk of cancer.

phytochemical A substance found in plant foods (*phyto-* means plant) that is not an essential nutrient but may have health-promoting properties.

energy-yielding nutrient A nutrient that can be metabolized to provide energy in the body.

macronutrient A nutrient needed by the body in large amounts. These include water and the energy-yielding nutrients: carbohydrates, lipids, and proteins.

micronutrient A nutrient needed by the body in small amounts. These include vitamins and minerals.

organic molecule A molecule that contains carbon bonded to hydrogen.

inorganic molecule A molecule that contains no carbon–hydrogen bonds.

kilocalorie (kcal, kcalorie) The unit of heat used to express the amount of energy provided by foods. It is the amount of heat required to raise the temperature of 1 kg of water 1 degree Celsius (1 kcal = 4.18 kJ).

kilojoule (kJ, kjoule) A unit of work that can be used to express energy intake and energy output. It is the amount of work required to move an object weighing 1 kg a distance of 1 meter under the force of gravity (1 kJ = 0.24 kcal).

The Six Classes of Nutrients

Chemically, there are six classes of nutrients: carbohydrates, lipids, proteins, water, vitamins, and minerals. These classes can be grouped in a variety of ways—by whether they provide energy to the body, by how much is needed in the diet, and by their chemical structure. Carbohydrates, lipids, and proteins provide energy and thus are referred to as **energy-yielding nutrients**. Alcohol also provides energy but is not considered a nutrient because it is not needed to support life (see Focus on Alcohol). Along with water, the energy-yielding nutrients constitute the major portion of most foods and are required in relatively large amounts by the body. Therefore, they are referred to as **macronutrients** (*macro-* means large). Their requirements are measured in kilograms (kg) or grams (g). Vitamins and minerals are classified as **micronutrients** because they are needed in small amounts in the diet (*micro-* means small). The amounts required are expressed in milligrams (1 mg = 1/1000 g) or micrograms (1 μg = 1/1,000,000 g) (see online Appendix I). Structurally, carbohydrates, proteins, lipids, and vitamins are **organic molecules**, so they are referred to as *organic nutrients*. Minerals and water are **inorganic molecules**, so they are referred to as *inorganic nutrients*.

The Energy-Yielding Nutrients The energy provided by carbohydrates, lipids (fats), and proteins is measured in **kilocalories** (abbreviated kcal or kcalories) or in **kilojoules** (abbreviated kJ or kjoules). The more common term, calorie (lowercase *c*), is technically 1/1000 of a kilocalorie, but when spelled with a capital *C*, Calorie means a kilocalorie (Figure 1.7). In the popular press, calorie (small *c*) is often used to express the kilocalorie content of a food or diet.

The grams of carbohydrate, fat, and protein determine the number of kcalories in a food.

Nutrition Facts
Serving Size 1 cup (236ml)
Servings Per Container 1

Amount Per Serving

Calories 121	Calories from Fat 45
	% Daily Value*
Total Fat 5g	**8%**
Saturated Fat 3g	**15%**
Trans Fat 0g	
Cholesterol 20mg	**7%**
Sodium 160mg	**7%**
Total Carbohydrate 11g	**4%**
Dietary Fiber 0g	**0%**
Sugars 5g	
Protein 8g	

Energy Provided by Macronutrients and Alcohol

	Kcalories/gram	Kjoules/gram
Carbohydrate	4	16.7
Protein	4	16.7
Fat	9	37.6
Alcohol	7	29.3

FIGURE 1.7 Calories in foods
The term "Calories" listed near the top of the Nutrition Facts panel on a food label technically refers to the number of kilocalories in a serving of the food. It is equal to the total number of kilocalories provided by the grams of carbohydrate, fat, and protein in a serving. Alcohol also provides calories but currently nutrition information is not required on the labels of alcoholic beverages. The number of kilocalories in a serving of the food from the label shown here can be calculated as follows: (5 g fat × 9 kcal/g) + (11 g carbohydrate × 4 kcal/g) + (8 g protein × 4 kcal/g) = 121 kcal per serving.

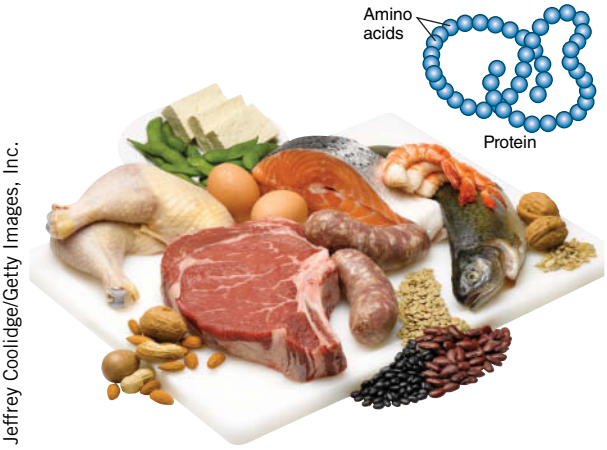
FIGURE 1.8 Carbohydrates, lipids, and proteins

Jeffrey Coolidge/Getty Images, Inc.

A. Carbohydrates include sugars, starches, and fiber. Pasta, rice, and bread contain mostly starch; whole-grain bread, oatmeal, and popcorn are high in fiber; and cookies, cakes, and sweetened beverages are high in added sugar.

Charles D. Winters/Science Source

B. Most of the lipids we consume in our food are triglycerides; each contains three fatty acids. Plant sources of triglycerides in our diet include vegetable oils, avocados, olives, and nuts. Animal sources of triglycerides include cream, butter, meat, and whole milk; these animal foods also provide cholesterol.



Jeffrey Coolidge/Getty Images, Inc.

C. Proteins are made of amino acids linked together. The proteins we obtain from animal foods, such as meat, fish, and eggs, better match our amino acid needs than do most individual plant proteins, such as those found in grains, nuts, and beans. However, when plant sources of protein are combined, they can provide all the amino acids we need.

Carbohydrates provide a readily available source of energy to the body. They contain 4 kcal/g (see Figure 1.7). Carbohydrates include sugars such as those in table sugar, fruit, and milk, and starches such as those in vegetables, **legumes**, and grains. Sugars are the simplest form of carbohydrate, and starches are more complex carbohydrates made of many sugars linked together (Figure 1.8A). Most fiber is also carbohydrate. Fiber cannot be digested and therefore provides very little energy. However, it is important for gastrointestinal health. Fiber is found in vegetables, fruits, legumes, and whole grains.

Lipids, commonly called fats and oils, provide 9 kcal/g. They are a concentrated source of energy in food and a lightweight storage form of energy in the body. Several types of lipids are important in nutrition. Triglycerides are the type that is most abundant in foods and in the body. The fat on the outside of a steak, the butter and oil that is added to food during cooking, and the layer of fat under a person's skin are all composed almost entirely of triglycerides. Triglycerides are made up of fatty acids (Figure 1.8B). Different types of fatty acids have different health effects. Diets high in saturated fatty acids increase the risk of heart disease, whereas those high in unsaturated fatty acids may reduce these risks. Cholesterol is another type of lipid; high levels in the blood can increase heart disease risk (see Chapter 5).

legumes Plants in the pea or bean family that produce an elongated pod containing large starchy seeds. Green peas, kidney beans, and peanuts are legumes.

Protein is needed for growth and maintenance of body structures and to regulate and facilitate body processes. It can also be used to provide energy—4 kcal/g. Meat, fish, poultry, eggs, milk, grains, vegetables, and legumes all provide protein. Like carbohydrate and lipid, protein is not a single substance. There are thousands of different proteins in the human body and in the diet. All of these are made up of units called amino acids. Different combinations of amino acids are linked together to form different types of proteins (Figure 1.8C). Some amino acids can be made by the body, and others are essential in the diet. The proteins in animal products better match our need for amino acids than do plant proteins, but both plant and animal proteins can provide all the amino acids we need.

Water Unlike the other classes of nutrients, water is only a single substance. Water makes up about 60% of an adult's body weight. Because we can't store water, the water the body loses must

constantly be replaced by water obtained from the diet. In the body, water acts as a lubricant, a transport fluid, and a regulator of body temperature, among other functions.

Micronutrients Vitamins and minerals are needed in small amounts. Vitamins are organic molecules that do not provide energy but are needed to regulate body processes. Thirteen substances have been identified as vitamins. Each has a different structure and provides a unique function in the body. Many are involved in providing energy from carbohydrates, lipids, and proteins; others function in processes such as bone growth, vision, blood clotting, oxygen transport, and tissue growth and development.

Minerals are inorganic molecules. Like vitamins, they do not provide energy. Many have regulatory roles, and some are important structurally. They are needed for bone strength, the transport of oxygen, the transmission of nerve impulses, and numerous other functions. Requirements have been established for many of the minerals, but some are required in such small amounts that their role in maintaining health is still not fully understood.

Vitamins and minerals are found in most foods. Fresh foods are a good natural source, and many processed foods are fortified with vitamins and minerals. Food processing and preparation can also cause vitamin losses because some vitamins are destroyed by exposure to light, heat, and oxygen. Minerals are more stable but can still be lost along with vitamins when food components are separated during processing and in the water used in cooking and processing.

What Nutrients Do

Together, the macronutrients and micronutrients provide energy, structure, and regulation, which are needed for growth, maintenance and repair, and reproduction. Each nutrient provides one or more of these functions, but all nutrients together are needed to maintain health (Figure 1.9).

Nutrients Provide Energy Inside the body, biochemical reactions release the energy contained in carbohydrates, lipids, and proteins. Some of this energy is used to synthesize new compounds and maintain basic body functions, some is used to fuel physical activity, and some is lost as heat. When the energy in the carbohydrates, lipids, and proteins consumed in the diet is not needed immediately, it can be stored, primarily as body fat. These stores can provide energy when dietary sources are unavailable. Over the long term, if more energy is consumed than is needed, body fat stores enlarge and body weight increases. If less energy is consumed than is needed, the body will burn its fat stores to meet its energy needs and body weight will decrease.

FIGURE 1.9 Nutrients provide energy, form structures, and regulate body processes

Wendy Hope/Stockbyte/Getty Images, Inc.

When body temperature increases, sweat is produced, cooling the body as the water evaporates from the skin.

Function	Nutrient	Example
Energy	Carbohydrate	Glucose is a carbohydrate that provides energy to body cells.
	Lipid	Fat is the most plentiful source of stored energy in the body.
	Protein	Protein consumed in excess of protein needs will be used for energy.
Structure	Lipid	Lipids are the principal component of the membranes that surround each cell.
	Protein	Protein in connective tissue holds bones together and holds muscles to bones. Protein in muscles defines their shape.
	Minerals	Calcium and phosphorus are minerals that harden teeth and bones.
Regulation	Lipid	Estrogen is a lipid hormone that helps regulate the female reproductive cycle.
	Protein	Leptin is a protein that helps regulate the size of body fat stores.
	Carbohydrate	Sugar chains attached to proteins circulating in the blood signal whether the protein should remain in the blood or be removed by the liver.
	Water	Water in sweat helps cool the body to regulate body temperature.
	Vitamins	B vitamins regulate the use of macronutrients for energy.
	Minerals	Sodium is a mineral that helps regulate blood volume.

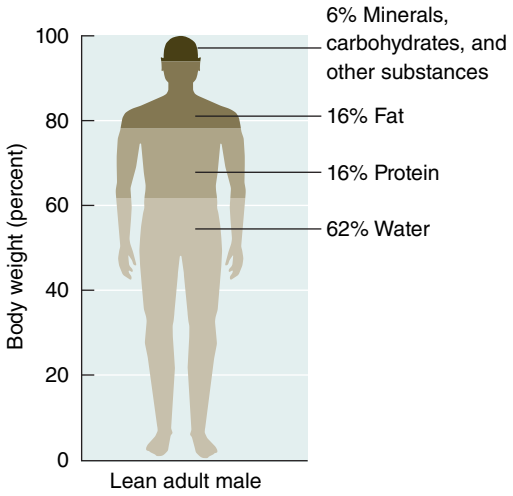


FIGURE 1.10 Composition of the human body
Minerals, carbohydrate, fat, protein, and water all contribute to the shape and structure of our bodies.

Nutrients Form Structures With the exception of vitamins, all the classes of nutrients are involved in forming and maintaining the body's structure (Figure 1.10). Fat deposited under the skin contributes to our body shape, for instance, and proteins form the ligaments and tendons that hold our bones together and attach our muscles to our bones. Minerals harden bone. Proteins and water make up the structure of the muscles, which help define our body contours, and proteins and carbohydrates form the cartilage that cushions our joints. On a smaller scale, lipids, proteins, and water form the structure of individual cells. Lipids and proteins make up the membranes that surround each cell, and water and dissolved substances fill the cells and the spaces around them.

Nutrients Regulate Body Processes All six classes of nutrients play important roles in regulating body processes (see Figure 1.9). To maintain life, body temperature, blood pressure, blood sugar level, and hundreds of other parameters must be kept relatively constant, a condition referred to as **homeostasis**. Maintaining homeostasis involves thousands of chemical reactions and physiological processes. Together all of the chemical reactions that occur in the body are referred to as **metabolism**. Proteins, vitamins, and minerals are regulatory nutrients that help control how quickly metabolic reactions take place throughout the body. Lipids and proteins are needed to make regulatory molecules that stimulate or inhibit various body processes.

homeostasis A physiological state in which a stable internal body environment is maintained.

metabolism The sum of all chemical reactions that take place in a living organism.

1.3 Nutrition and Health

LEARNING OBJECTIVES

- Define *malnutrition*.
- Discuss how under- and overnutrition can affect your health in the short term and in the long term.
- Discuss how the genes you inherit affect the impact your diet has on your health.
- Define *nutrient density*.
- Explain the importance of variety, balance, and moderation in selecting a healthy diet.

What we eat has an enormous impact on how healthy we are now and how likely we are to develop chronic diseases like heart disease, obesity, and diabetes in the future. Consuming either too little or too much of one or more nutrients or energy will cause **malnutrition**. Malnutrition can affect our health today and can impact our health 20, 30, or 40 years from now. Avoiding malnutrition and nutrition-related diseases requires choosing a dietary pattern that meets our nutrient and energy needs. The pattern that is optimal varies from person to person depending on the individual's genetic makeup.

malnutrition Any condition resulting from an energy or nutrient intake either above or below that which is optimal.

How Undernutrition Affects Health

undernutrition Any condition resulting from an energy or nutrient intake below that which meets nutritional needs.

Undernutrition is a form of malnutrition caused by a deficiency of energy or nutrients. It may be caused by a deficient intake, increased requirements, or an inability to absorb or use nutrients. Starvation, the most severe form of undernutrition, is a deficiency of energy that causes weight loss, poor growth, the inability to reproduce, and if severe enough, death (Figure 1.11A). Deficiencies of individual nutrients can also cause serious health problems. The symptoms of nutrient deficiencies often reflect the functions of the deficient nutrient. For example, vitamin A is necessary for vision; a deficiency of vitamin A can result in blindness. Vitamin B_{12} is needed for normal nerve function. A deficiency of this vitamin, which is more common in older adults because absorption often decreases with age, causes numbness, tingling, and other neurological symptoms.

Some nutrient deficiencies cause symptoms quickly. In only a matter of hours, an athlete exercising in hot weather may become dehydrated due to a deficiency of water. Drinking water

FIGURE 1.11 Starvation and obesity are both forms of malnutrition

Wesley Bocxe/Photo Researchers, Inc.

A. The symptoms of starvation, the most obvious form of undernutrition, occur gradually over time when the energy provided by the diet is too low to meet the body's needs. Body tissues are broken down to provide the energy to support vital functions, resulting in loss of body fat and wasting of muscles.

© Dennis MacDonald/Age Fotostock America, Inc.

B. Obesity is a form of overnutrition that occurs when energy intake surpasses energy expenditure over a long period, causing the accumulation of an excessive amount of body fat. Today over a third of adults and an estimated 17% of U.S. children and adolescents ages 2 to 19 years have so much excess body fat that they are classified as obese.[7]

relieves the headache, fatigue, and dizziness caused by dehydration almost as rapidly as these symptoms appeared. Other nutritional deficiencies may take much longer to become apparent. Symptoms of scurvy, a disease caused by a deficiency of vitamin C, appear after months of deficient intake; osteoporosis, a condition in which the bones become weak and break easily, occurs after years of consuming a calcium-deficient diet.

How Overnutrition Affects Health

Overnutrition, an excess of energy or nutrients, is also a form of malnutrition. When excesses of specific nutrients are consumed, an adverse or toxic reaction may occur. For example, a single excessive dose of iron can cause liver failure, and too much vitamin B_6 can cause nerve damage. These nutrient toxicities usually result from taking large doses of vitamin and mineral supplements. Foods generally do not contain high enough concentrations of nutrients to be toxic.

overnutrition Poor nutritional status resulting from an energy or nutrient intake in excess of that which is optimal for health.

The type of overnutrition that is most common in the United States today does not have immediate toxic effects but contributes to the development of chronic diseases in the long term. The typical U.S. diet, which provides more calories than are needed, has resulted in an epidemic of obesity in which more than 68% of adults are overweight or obese (Figure 1.11B).[7] Diets that are high in sodium contribute to high blood pressure; an excess intake of saturated fat contributes to heart disease; and a dietary pattern that is high in red meat and saturated fat and low in fruits, vegetables, and fiber may increase the risk of certain cancers.[5]

How Our Diets Interact with Our Genetic Makeup

What we eat affects our health, but diet alone does not determine whether we will develop a particular disease. Each of us inherits a unique combination of **genes**. Some of these genes affect our risk of developing chronic diseases such as heart disease, cancer, high blood pressure, and diabetes, but their impact is affected by what we eat. Our genetic makeup determines the impact a certain nutrient will have on us. For example, some people inherit a combination of genes that

genes Units of a larger molecule called DNA that are responsible for inherited traits.

makes their blood pressure more sensitive to the amount of sodium in their diet. When these individuals consume even an average amount of sodium, their blood pressure increases (as discussed further in Chapter 10). Others inherit genes that allow them to consume more sodium without a rise in blood pressure. Those who inherit "salt sensitivity" can reduce their blood pressure, and the complications associated with high blood pressure, by eating a diet that is low in sodium.

nutritional genomics The study of how our genes affect the impact of nutrients or other food components on health (nutrigenetics) and how nutrients affect the activity of our genes (nutrigenomics).

Our increasing understanding of human genetics has given rise to the discipline of **nutritional genomics**, which explores the interaction between human genes and nutrition and health.[14] It encompasses both the effect that the genes a person inherits have on how his or her diet affects health (nutrigenetics) and the effect the nutrients and other food components that he or she consumes has on gene activity (nutrigenomics) (Figure 1.12). Research in these areas has led to the development of the concept of "personalized nutrition." The goal of personalized nutrition is to prescribe a diet based on the genes an individual has inherited in order to prevent, moderate, or cure chronic disease. Although today we do not have the tools to take a sample of everyone's DNA and use it to tell them what to eat to optimize their health, we do know that certain dietary patterns can reduce the risk of many chronic diseases (see **Debate: Is There a "Best" Diet for You?**)

How to Choose a Healthy Diet

Each of the food choices we make contributes to our diet as a whole (see **How to Choose: Healthy Meals Away from Home**). No single food choice is good or bad in and of itself, but all of our choices combined make up a dietary pattern that is either healthy or not so healthy. A healthy diet is one that provides the right amount of energy to keep weight in the desirable range; the proper types and balance of carbohydrates, proteins, and fats; plenty of water; and sufficient but not excessive amounts of essential vitamins and minerals. A healthy diet is rich in nutrient-dense foods such as whole grains, fruits, vegetables, lean meats, seafood, nuts and seeds, and low-fat dairy products.

nutrient density An evaluation of the nutrient content of a food in comparison to the calories it provides.

Nutrient density is a measure of the nutrients a food provides compared to its energy content. Nutrient-dense foods contain more nutrients per calorie than do foods with a lower nutrient density. For example, a glass of low-fat milk is a more nutrient-dense choice than a

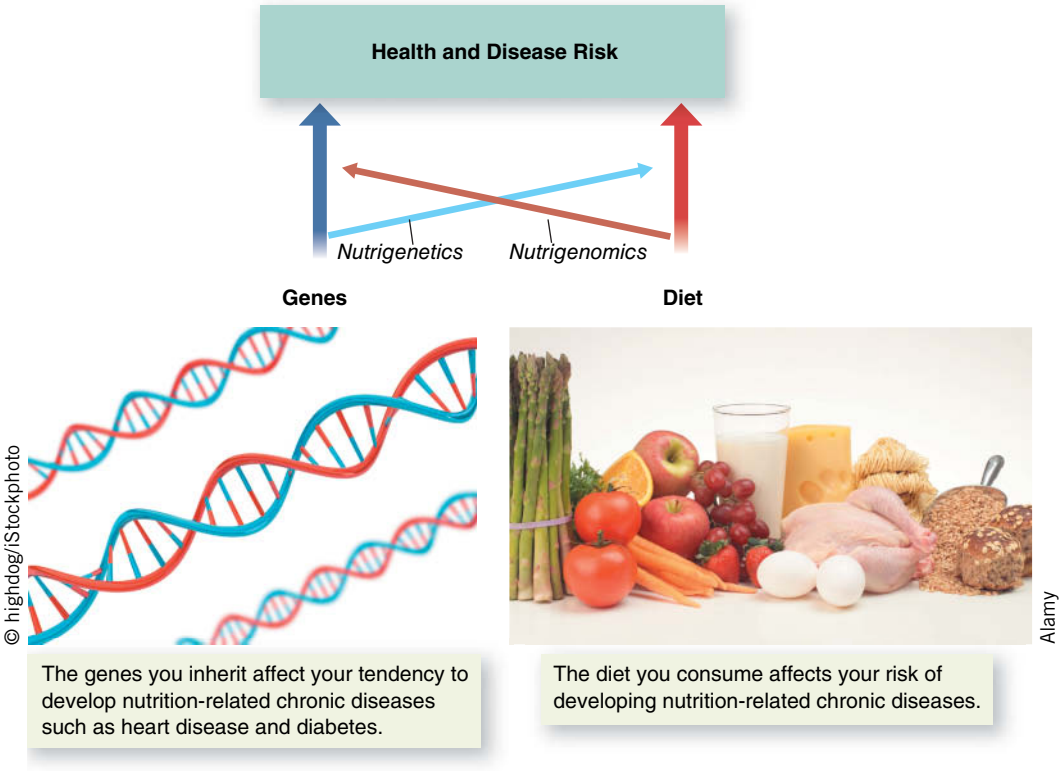


FIGURE 1.12 Diet, genes, and health Both the genes you inherit and your diet and lifestyle choices directly affect your health and disease risk. There is also interplay between these such that your genes, through nutrigenetics, influence how your diet affects your health, and your diet, through nutrigenomics, affects how your genes impact your health.

DEBATE

Is There a "Best" Diet for You?

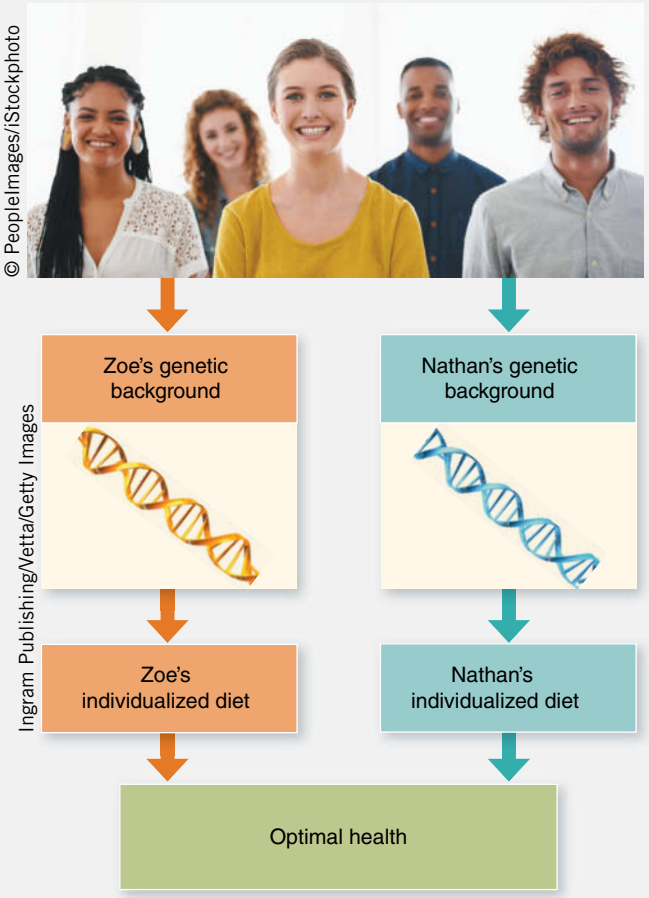
What is the best diet for you? That depends on who you are, your current health status, and your health risks. Much of this is determined by your genetic background. Do your parents have diabetes or heart disease? If the answer is yes, you are at risk. Is everyone in your family overweight? If they are, you may be headed there too. The new science of nutritional genomics suggests that you can reduce your risk of disease by tailoring your diet to your individual genetic makeup (see figure).[15] It predicts that someday you may go to the doctor's office, have your genes analyzed, and then have specific foods and dietary supplements prescribed to optimize your health. Are such genetically customized foods and diets the next big advance in public health, or are we better off sticking to general dietary recommendations that can be applied to everyone?

Current nutrition guidelines are designed to improve and maintain the health of almost all healthy people in the population. Yet we know that different people respond differently to the same diet, so dietary advice that is good for the majority of people may not be optimal for each individual. Modern medicine is already practicing nutritional genomics at a very basic level; dietitians design special diets based on patients' existing medical conditions. People with elevated blood lipid levels are instructed to reduce their intake of saturated fat and increase their fiber intake, those with high blood pressure are shown how to reduce their salt intake, and people with diabetes are taught how to manage blood sugar levels by modifying their carbohydrate intake.

Proponents of nutritional genomics suggest that reviewing an individual's genetic analysis will permit the development of more personalized dietary recommendations and these will prevent or improve outcomes for a variety of chronic diseases.[16] These diets could be customized to take into consideration individual genetic variations in disease as well as life stage, dietary preferences, and other aspects of health status.[17] Some propose that if followed, these personalized recommendations may supplement and even replace prescription drugs.

Would the benefit of these individualized diet plans justify the expense of the genetic analyses? Some argue that this approach is unlikely to improve individual or public health.[18] Many people fail to follow current population-wide nutrition guidelines for a healthy diet, not because they lack the knowledge, money, or motivation to do so, but simply because they choose not to. Therefore, it is unlikely that they will follow personalized guidelines any better or that genetic test results will motivate them to eat a healthier diet.[19,20] The priority for public health should not be to fine-tune diet prescriptions but to find out what will make people change their diets and live healthier lives.

Other concerns with nutritional genomics are the ethics of widespread genetic testing and the possibility that commercial interests will drive nutritional genomics rather than any benefits to public health.[20] People who strictly follow their diet prescriptions will certainly benefit, but the big beneficiaries



of personalized diet prescriptions will be biotech companies, which would profit from the genetic testing needed to establish disease profiles, and the food industry, which would benefit from the creation and sale of foods designed to treat disease.[18] There is also concern that personalized nutrition will be very costly, perhaps reserved for those with money and education.[17]

In the future, will we select breakfast cereals and dietary supplements based on our genes? Will these choices, which target the prevention of some potential chronic diseases, increase the risk of others? Will following personalized dietary prescriptions make us healthier than just choosing an overall healthy diet? In choosing foods based on nutritional genomics, will we lose track of the pleasure we get from food and the cultural and social roles that food plays in our lives?

THINK CRITICALLY: If genetic testing determines that you are at low risk for heart disease, does this mean that you can ignore the public health recommendation to limit saturated fat intake? Why or why not?

HOW TO CHOOSE Healthy Meals Away from Home

Fast food

- Skip the breaded and fried chicken and choose broiled instead.
- Choose a plain burger rather than one with extra sauce and cheese.
- Split an order of fries with a friend or choose a salad instead.
- Top your pizza with vegetables rather than meat and skip the extra cheese.

Standard American fare

- Avoid buffets and all-you-can-eat specials.
- Order a baked potato instead of French fries.
- Avoid thick buttery, creamy, and cheesy sauces.
- Trim the fat from meat and remove the skin from poultry.
- Order your protein grilled, broiled, flame-cooked, steamed, poached, roasted, or baked.
- Order your salad dressing on the side—then you can choose how much you add.

Ethnic choices

- Chinese: Choose items with large portions of vegetables and skip the fried wontons, dumplings, and egg rolls.
- Italian: Have a red sauce instead of high-fat alfredo sauce on your pasta.
- Mexican: Go easy on chips and order fajitas instead of the fried items such as chile rellenos, chorizo, chimichangas, or flautas.
- Indian: Choose dishes with lentils and vegetables and avoid ghee (clarified butter) and cream sauces such as korma. Choose tikka and tandoori and kabob preparations and avoid crispy dishes.
- Middle Eastern: Have hummus with pita, yogurt sauce (tzatziki sauce), eggplant, and other vegetable dishes, and avoid fatty gyros, fried falafel, and baklava.

soft drink or a glass of sugar-sweetened iced tea (**Figure 1.13A**). If a large proportion of your diet is made up of foods that are low in nutrient density, such as candy, soft drinks, snack foods, and baked goods, you could have a hard time meeting your nutrient needs without exceeding your calorie needs. By choosing nutrient-dense foods, you can meet all your nutrient needs and have calories left over for occasional treats that are lower in nutrients and higher in calories (**Figure 1.13B**).

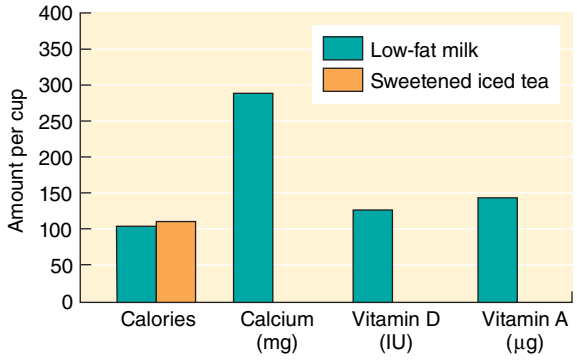
A healthy diet is based on variety, balance, and moderation. Using these principles, you can develop a personal strategy for making better choices and maintain your health for the long term.

Eat a Variety of Foods No one food can provide all the nutrients the body needs for optimal health. Eating a variety of foods, however, helps ensure an adequate nutrient intake. Variety means choosing foods from different food groups—vegetables, grains, fruits, dairy products, and high-protein foods. Some of these groups are good sources of carbohydrate, fiber, and vitamins; others are rich in minerals and phytochemicals. All are important.

Variety also means choosing different foods from within each food group. For instance, if you choose three servings of vegetables a day and they are all carrots, it is unlikely that you will meet your nutrient needs. Carrots provide fiber and vitamin A but are a poor source of vitamin C. If instead you have carrots, peppers, and broccoli, you will be getting vitamin C along with more vitamin A, vitamin K, fiber, and phytochemicals than carrots alone would provide. Likewise, if you always choose red meat as a protein source, you will be missing out on the fiber in beans and the healthy fats in nuts and fish. Variety comes from choosing different foods not only each day but also each week and each season. If you had apples and grapes today, have blueberries and cantaloupe tomorrow. If you can't find tasty tomatoes in December, replace them with a winter vegetable like squash.

Choosing a varied diet is also important because of the interactions between different foods and nutrients. These interactions may be positive, enhancing nutrient utilization, or negative, inhibiting nutrient use. For example, consuming iron with orange juice enhances

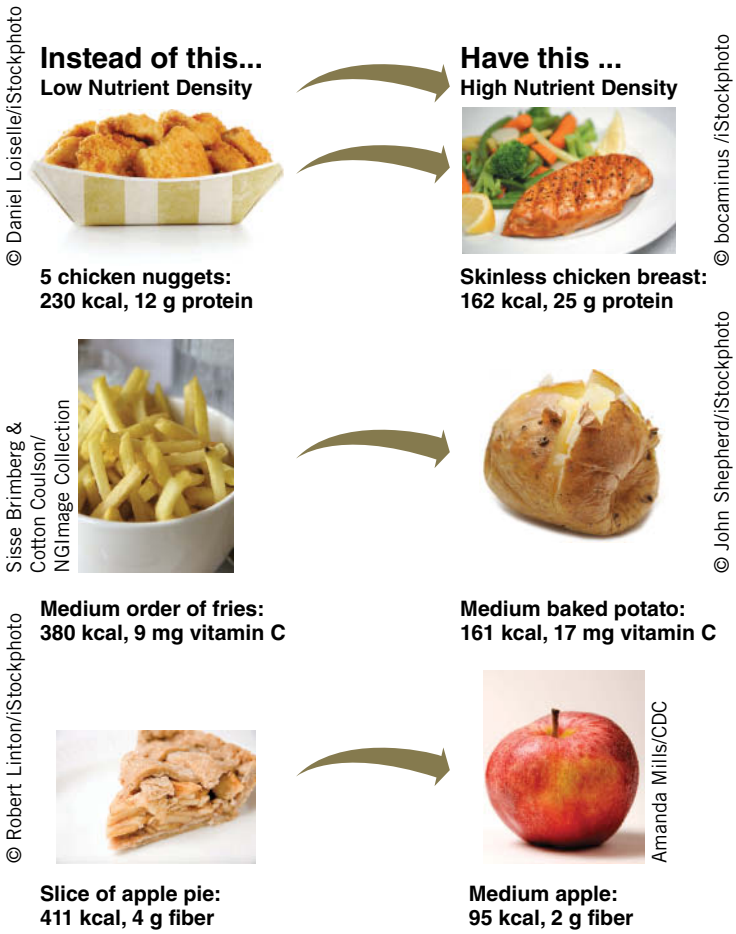
FIGURE 1.13 Nutrient-dense diets provide more nutrients per calorie



A. Nutrient density is important in choosing a healthy diet. For example, low-fat milk is higher in nutrient density than sweetened iced tea. Although it provides about the same number of calories per cup as the tea, it also provides calcium, vitamin D, vitamin A, and other nutrients, including protein.

THINK CRITICALLY

The slice of apple pie has twice as much fiber as the apple, so why is the apple considered the more nutrient-dense choice?



B. Typically, less processed foods are higher in nutrient density. For example, a roasted chicken breast is more nutrient dense than chicken nuggets; a baked potato is more nutrient dense than French fries; and an apple is more nutrient dense than apple pie.

iron absorption, while consuming iron with milk may reduce its absorption. In a varied diet these interactions balance out. In addition, some foods may contain natural toxins or residues of pesticides, fertilizers, and other toxic substances (see Chapter 17). Choosing a variety of foods avoids an excess of any one of these substances. For example, tuna may contain traces of mercury, but as long as you don't eat tuna too often, you are unlikely to consume a toxic amount.

Balance Your Choices Choosing a healthy diet is a balancing act. Healthy eating doesn't mean giving up your favorite foods. There is no such thing as a good food or a bad food—only healthy diets and unhealthy diets. Any food can be part of a healthy diet as long as overall intake over the course of days, weeks, and months provides enough of all of the nutrients needed without excesses of any. When you choose a food, like white rice, that is lacking in fiber, balance this choice with one, like oatmeal, that provides lots of fiber. When you choose a food that is high in fat, like cheese, then balance that choice with a low-fat one, like a piece of fruit. Balancing your choices allows foods that would not usually be considered healthy choices to fit into an overall healthy diet. For example, baked goods, snack foods, and sodas should be balanced with nutrient-dense choices such as salads, fresh fruit, and low-fat dairy products. If your favorite meal is a burger, French fries, and a milkshake, enjoy it but balance it with asparagus, brown rice, and baked chicken at the next meal.

Balance involves mixing and matching foods in proportions that allow you to get enough of the nutrients you need and not too much of ones that might harm your health. A balanced diet provides plenty of whole grains, fruits, and vegetables. It contains enough but not too much of

If you have a Big Mac for lunch instead of a smaller plain burger, you will have to increase your energy expenditure by 300 kcal.

Andy Washnik

Picturenet/Blend Images/Getty Images, Inc.

You could do this by playing golf for about an hour, carrying your own clubs.

If you have a grande Mocha Frappuccino instead of a regular iced coffee, you will have to increase your energy expenditure by 370 kcal.

Andy Washnik

Kate Thompson/NG Image Collection

You could do this by jogging for about 30 minutes.

FIGURE 1.14 Balance calories in with calories out
To keep your weight stable, you need to burn the same number of calories as you consume. Extra calories you consume during the day can be balanced by increasing the calories you burn in physical activity.

each of the vitamins and minerals, as well as protein, carbohydrate, fat, and water. It also balances the energy taken in with the energy used in daily activities so body weight stays in the healthy range (Figure 1.14).

Everything in Moderation Moderation means everything is okay, as long as you don't overdo it. Moderation means not consuming too much energy, too much fat, too much sugar, too much salt, or too much alcohol, whether you are eating at home or away from home (see How to Choose: Healthy Meals Away from Home). It means watching your portion sizes. Have you ever sat down in front of the TV with a bag of chips, and before you knew it half the bag was gone? If you have, then you know how easy it is to let portion sizes get out of control. Choosing moderately will help you maintain a healthy weight and help prevent some of the chronic diseases like heart disease and cancer that are on the rise in the U.S. population. The fact that more Americans are obese than ever before demonstrates that we have not been practicing moderation when it comes to energy intake. Moderation will make it easier to balance your diet and will allow you to enjoy a greater variety of foods.

1.4 The Science Behind Nutrition

LEARNING OBJECTIVES

- List the steps of the scientific method.
- Compare the type of information obtained from epidemiology to that obtained from human intervention or laboratory studies.
- Discuss why animals and cells are used to study human nutrition.
- Discuss how the ethics of human and animal studies are monitored.

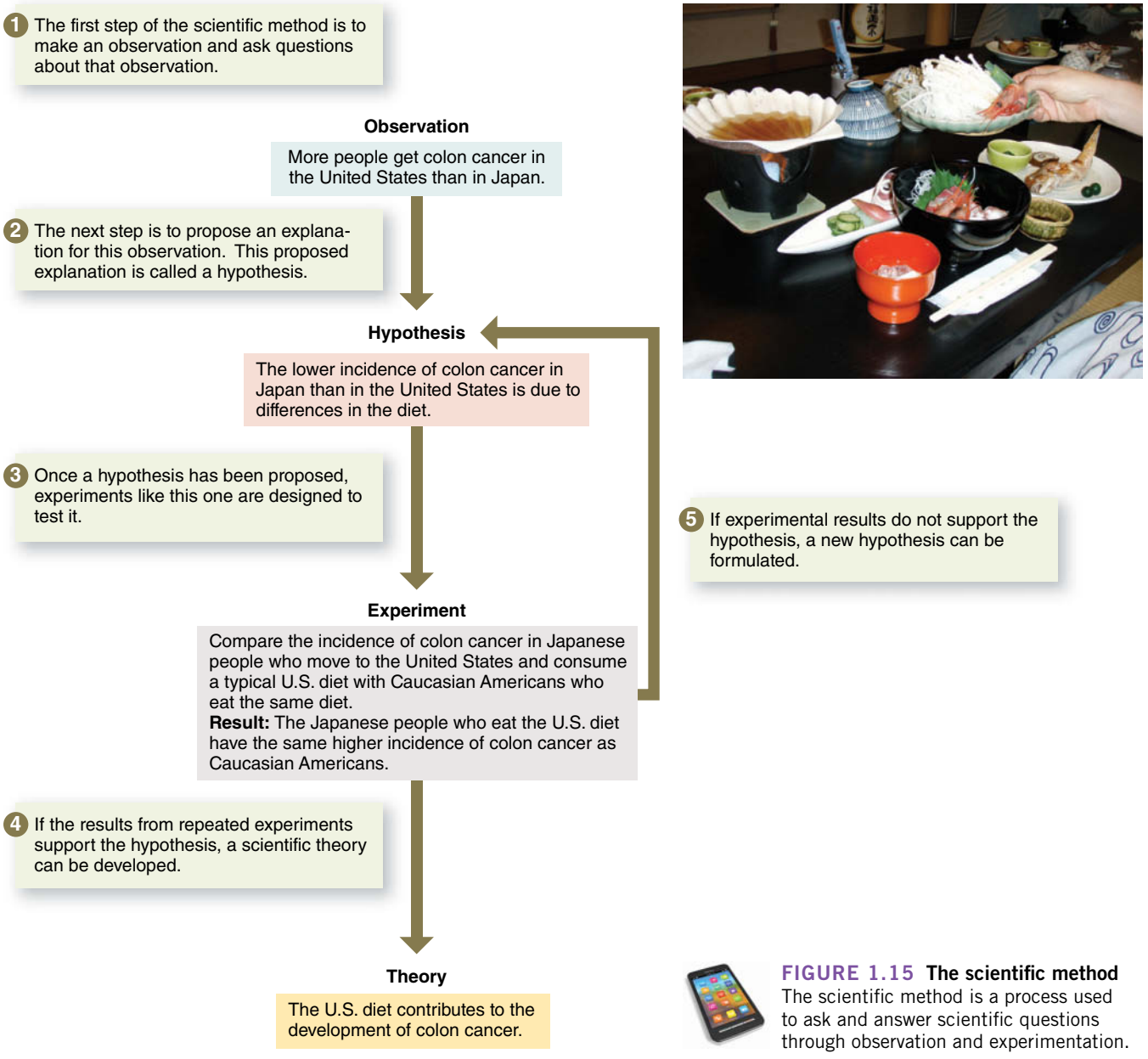
Nutrition, like all science, continues to develop as new discoveries provide clues to the right combination of nutrients needed for optimal health. As knowledge and technology advance, new nutrition principles are developed. Sometimes established beliefs and concepts must give way to new ideas, and recommendations change. Today more and more consumers are seeking information about nutrition and how to improve their diets.[1] But many people find it difficult to tell what information is accurate and what is exaggerated. Developing an understanding of the process of science and how it is used to study the relationship between nutrition and health can help consumers make wise nutrition decisions, whether they involve what to have for breakfast or whether a headline about vitamin E supplements is true.

The Scientific Method

Advances in nutrition are made using the **scientific method** (Figure 1.15). The scientific method offers a systematic, unbiased approach to evaluating the relationships among food, nutrients, and health. The first step of the scientific method is to make an observation and ask questions about the observation. The next step is to propose a **hypothesis**, or explanation for the observation. Once a hypothesis has been proposed, experiments can be designed to test it. The experiments

scientific method The general approach of science that is used to explain observations about the world around us.

hypothesis An educated guess made to explain an observation or to answer a question.



Lori Smolin

FIGURE 1.15 The scientific method
The scientific method is a process used to ask and answer scientific questions through observation and experimentation.

theory An explanation based on scientific study and reasoning.

must provide objective results that can be measured and repeated. If the experimental results do not prove the hypothesis to be wrong, a **theory**, or a scientific explanation based on experimentation, can be established. Scientific theories are accepted only as long as they cannot be disproved and continue to be supported by all new evidence that accumulates. Even a theory that has been accepted by the scientific community for years can be proved wrong.

How Scientists Study Nutrition

Nutrition research studies are done to determine nutrient requirements, to learn more about the metabolism of nutrients, and to understand the role of nutrition in health and disease. Perfect tools do not exist for addressing all these questions. However, there are many types of research studies that can be useful in understanding the relationships between humans and their nutrient intake.

epidemiology The study of the interrelationships between health and disease and other factors in the environment or lifestyle of different populations.

Observational Studies Some of our nutrition knowledge has been obtained by observing relationships between diet and health in different populations throughout the world. This study of diet, health, and disease patterns is called **epidemiology**. Epidemiology does not determine cause and effect relationships—it just identifies patterns (Figure 1.16). For instance,

ANALYZE THE DATA

Does the data from these maps mean that inactivity is the cause of obesity? Will everyone who is inactive be obese?

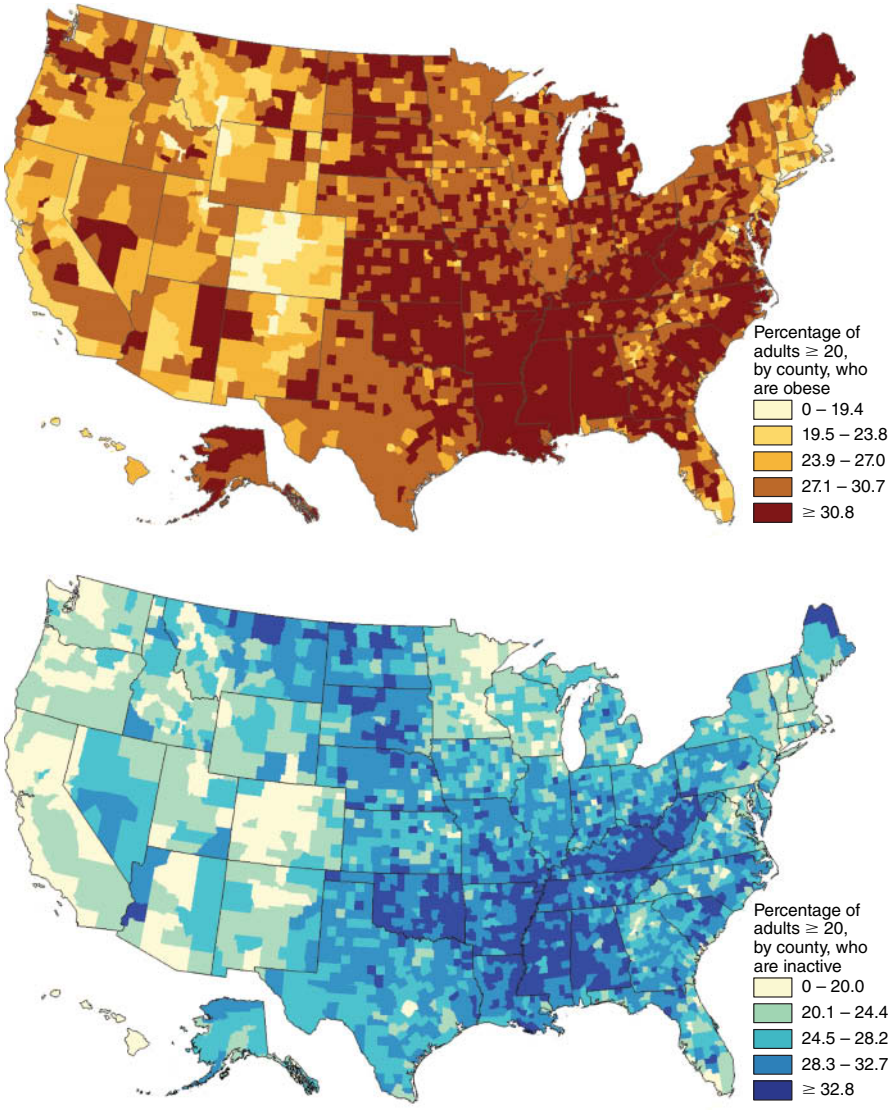


FIGURE 1.16 Does inactivity cause obesity?
These maps were created using epidemiological data. They show that the prevalence of obesity (top map) roughly mirrors the prevalence of inactivity (bottom map) in counties across the United States.

by comparing diets in different countries with the incidence of cancer, scientists were able to identify an association, or **correlation**, between diets high in fruits and vegetables and a lower incidence of cancer. Some epidemiological studies collect data from a cross section of the population at one point in time, whereas others collect data from the same individuals over a long period of time (see **Science Applied: How Epidemiology Led to Dietary Recommendations for Heart Disease**).

correlation Two or more factors occurring together.

Case-control studies are a type of epidemiological study that compares individuals with a particular condition to similar individuals without the condition. For example, a case-control study of colon cancer might include a comparison of the dietary intake of a 45-year-old African American man with colon cancer to a man of the same age and ethnic background who is free of the disease. If a pattern, such as a higher fat intake among the cancer patients, is found in comparing cases to controls, a hypothesis can be proposed. Hypotheses based on case-control studies and other types of epidemiology must then be tested by controlled intervention and laboratory studies.

case-control study A type of observational study that compares individuals with a particular condition under study with individuals of the same age, gender, and background who do not have the condition.

Human Intervention Studies

The observations and hypotheses that arise from epidemiology can be tested using **human intervention studies**, often referred to as **clinical trials**. This type of experiment actively intervenes in the lives of a population and examines the effect of this intervention (see **Critical Thinking: Early Science**). Nutrition intervention studies generally explore the effects of altering people's diets. For example, if it is determined by epidemiology that populations eating a diet low in saturated fat have a lower incidence of heart disease, an intervention trial may be designed with an **experimental group** that consumes a diet lower in saturated fat than is typical in the population and a **control group** that consumes the typical diet. The groups can be monitored to see if the dietary intervention affects the incidence of heart disease over the long term.

human intervention study or **clinical trial** A study of a population in which there is an experimental manipulation of some members of the population; observations and measurements are made to determine the effects of this manipulation.

experimental group In a scientific experiment, the group of participants who undergo the treatment being tested.

control group In a scientific experiment, the group of participants used as a basis of comparison. They are similar to the participants in the experimental group but do not receive the treatment being tested.

Laboratory Studies

Laboratory studies are conducted in research facilities such as hospitals and universities. They are used to learn more about how nutrients function and to evaluate the relationships among nutrient intake, levels of nutrients in the body, and health. They may study nutrient requirements and functions in whole organisms—either humans or animals—or they may focus on nutrient functions at the cellular, biochemical, or molecular level.

How Whole Organisms Are Used to Study Nutrition

Many nutrition studies are done by feeding a specific diet to a person or animal and monitoring the physiological effects of that diet. **Depletion-repletion studies** are a classic method for studying the functions of nutrients and estimating the requirement for a particular nutrient. This type of study involves depleting a nutrient by feeding experimental subjects a diet devoid of that nutrient. After a period of time, if the nutrient is essential, symptoms of a deficiency will develop. The symptoms provide information on how the nutrient functions in the body. The nutrient is then added back to the diet, or repleted, until the symptoms are reversed. The requirement for that nutrient is the amount needed to reverse or prevent the deficiency symptoms. An example of a depletion-repletion study might be to feed animals a diet devoid of vitamin A for several weeks and examine the deficiency symptoms that appear. Then, if vitamin A is incrementally added back to the diet, the amount that prevents deficiency symptoms can be identified.

depletion-repletion study A study that feeds a diet devoid of a nutrient until signs of deficiency appear and then adds the nutrient back to the diet to a level at which symptoms disappear.

Another method for determining nutrient functions and requirements is to compare the intake of a nutrient with its excretion. This type of study is known as a **balance study**. If more of a nutrient is consumed than is excreted, balance is positive and it is assumed that the nutrient is being used or stored by the body. If more of the nutrient is excreted than is consumed, balance is negative, indicating that some is being lost from the body. When the amount consumed equals the amount lost, the body is neither gaining nor losing that nutrient and is said to be in a steady state or in balance. By varying the amount of a nutrient consumed and then measuring the amount excreted, it is possible to determine the minimum

balance study A study that compares the total amount of a nutrient that enters the body with the total amount that leaves the body.

SCIENCE APPLIED

How Epidemiology Led to Dietary Recommendations for Heart Disease

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

As early as the 1930s, scientists and physicians noticed that the incidence of heart disease was different in different countries and varied with social class and occupation.[21] In the 1940s, Professor Ancel Keys observed that well-fed American businessmen had high rates of heart disease, while the rate of heart disease had decreased in postwar Europe where food supplies were low. This led Keys to hypothesize that diet affected the risk of heart disease and to launch a series of epidemiological studies that changed the way we manage heart disease.

Pixtal/SuperStock

The vegetables, fruit, fish, and olive oil shown here are plentiful in the diet of countries around the Mediterranean Sea—where the Seven Countries Study found the incidence of coronary heart disease to be low. This dietary pattern, now known as the "Mediterranean diet," is one of the dietary patterns currently recommended for reducing the risk of heart disease.

THE SCIENCE

To test the diet and heart disease hypothesis, Keys began a study that collected annual physiological and lifestyle data on 500 healthy businessmen in Minnesota. He knew that over time some would develop heart disease and others would not. He hoped that comparing the data from afflicted men with that from healthy men would identify which characteristics were related to the development of the disease.[22] Key's study was what we call a prospective study: one that follows people over time and relates outcomes, such as the development of heart disease, to other factors such as body weight, blood cholesterol, or diet. The aim was to identify how those who developed heart disease differed from those who escaped it.

The Minnesota businessmen study provided Keys with the groundwork for a much larger epidemiological study called the Seven Countries Study, which was designed to compare characteristics among populations across a wide spectrum of diet and lifestyle. Between 1958 and 1964 the Seven Countries Study enrolled 12,763 men, ages 40 to 59 years, from 16 different regions within seven countries on three continents. The study evaluated health status, dietary intake, body weight, blood pressure, blood cholesterol level, and other health-related parameters at regular intervals. Patterns began to emerge. In northern European countries, the diet was high in dairy products; in the United States, it was high in meat; in southern Europe, it was high in vegetables, legumes, fish, and wine; and in Japan, it was high in cereals, soy products, and fish.[23] After 10 years, 1512 of the study participants were dead—413 of them from coronary heart disease[24]—but mortality differed strikingly with location. The island of Crete had only one coronary death out of 686 men studied, whereas eastern Finland had 78 coronary deaths among 817 participants.[25]

The coronary death rate was correlated with the average percentage of calories from saturated fat. In places such as Japan and the Greek islands, where the diet was low in saturated fat, blood cholesterol levels were lower, as was the risk of dying from heart disease. In countries such as Finland and the United States, where the diet was higher in saturated fat, blood cholesterol levels were higher, as was the incidence of heart disease. The results showed that blood cholesterol was strongly correlated with coronary heart disease deaths both for populations and for individuals. Some of the difference in the incidence of heart disease between countries was not explained by risk factors, but within a population risk factors such as diet, blood cholesterol, blood pressure, and cigarette smoking did predict risk.

THE APPLICATION

The Seven Countries Study and other epidemiological investigations have established the major risk factors for heart disease. These findings have helped develop individual dietary and lifestyle recommendations to treat people at high risk for heart disease as well as population-wide guidelines to promote public health. Heart disease is still the leading cause of death in the United States, but since 1950, age-adjusted death rates from cardiovascular disease have declined 60%. This is considered one of the most important public health achievements of the 20th century. The decline is due in part to fewer people smoking, better health care, and the use of antihypertensive and cholesterol-lowering drugs, but changes in diet based on the results of the Seven Countries Study and other epidemiological studies have also had an impact.[26]

CRITICAL THINKING

Early Science

Foodcollection/Getty Images

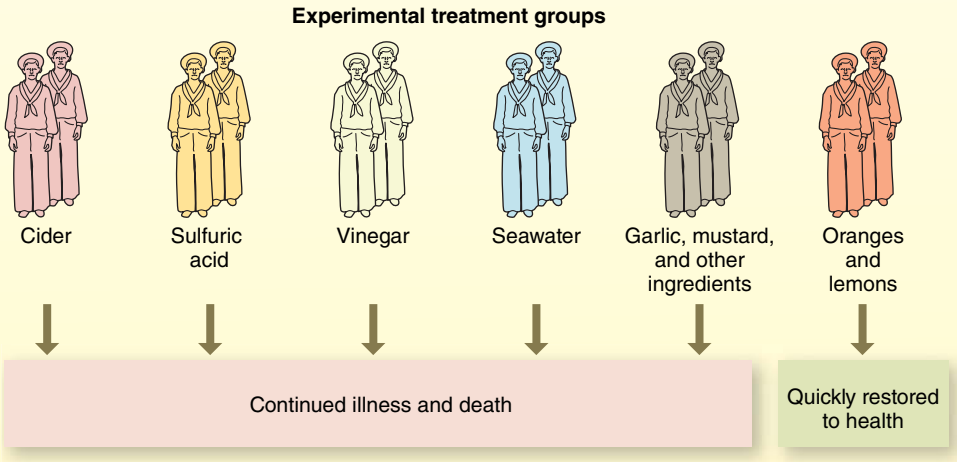
When explorers began making long sea voyages in the 1400s, it was observed that after about 12 weeks at sea the sailors began getting the symptoms of the disease scurvy. We know today that scurvy is due to a deficiency of vitamin C, but at the time Scottish physician James Lind was looking for a cure for the disease, vitamins had not even been discovered. Lind hypothesized that scurvy was caused by lack of acid in the body.

In 1747, Lind set up an experiment involving 12 sailors suffering from scurvy. He divided them into six groups. They were all fed the same diet that today we know was lacking in vitamin C, also known as ascorbic acid. He supplemented each group with a different substance. Most were acids, such as vinegar, dilute sulfuric acid, and cider. One group received lemons and oranges, which are high in ascorbic acid.

▼

What kind of study is this? Is the study well controlled?

After only a week the health of the group eating lemons and oranges was much improved, while sailors in the other groups remained ill and many died.



CRITICAL THINKING QUESTIONS

- **Did the experimental results support Lind's hypothesis? Why or why not?**

Based on the study results, one might hypothesize that scurvy is due to an absence of fruit in the diet.

- **Design a study to test the hypothesis that scurvy is caused by a lack of any type of fruit.**

iProfile Use iProfile to find vegetables that are good sources of vitamin C.

amount of that nutrient needed to replace body losses. This type of study can be used to determine protein requirements because protein is not stored in the body. It is not useful for determining the requirements for nutrients such as fat and iron that are stored when an excess is available (Figure 1.17).

Why Animals Are Used to Study Human Nutrition Ideally, studies of human nutrition would be done in humans. However, because studying humans is costly, time consuming,

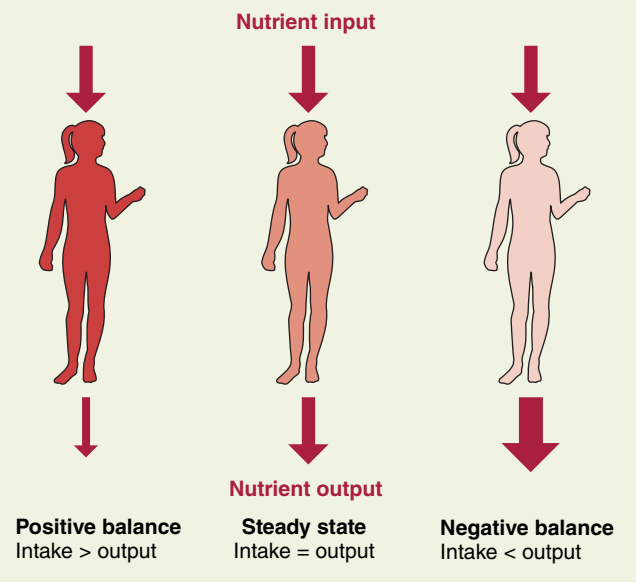
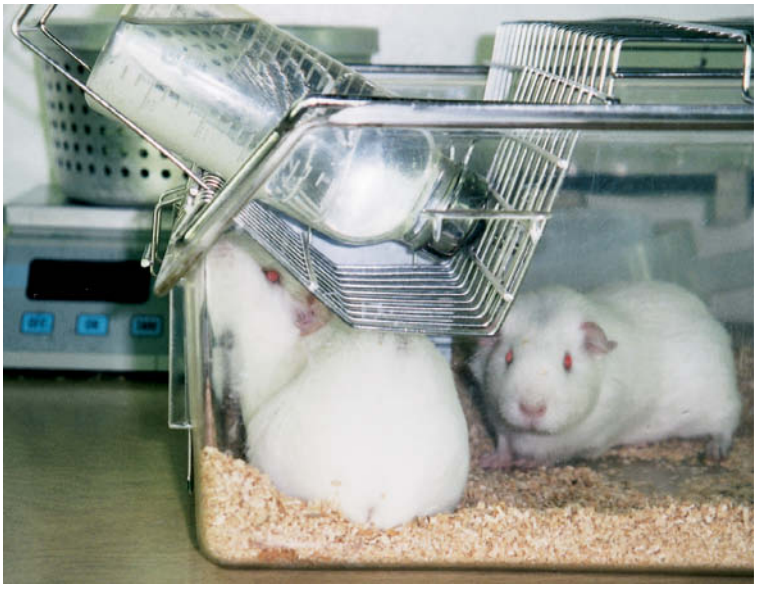


FIGURE 1.17 Balance studies
Nutrient balance studies compare the amount of a nutrient that is consumed with the amount excreted to determine whether the amount of the nutrient in the body is increasing (positive balance), remaining constant (balance, or steady state), or decreasing (negative balance).

inconvenient for subjects, and in some cases impossible for ethical reasons, many studies are done using experimental animals.

An ideal animal model is one with metabolic and digestive processes similar to those of humans. For example, cows are rarely used in human nutrition research because they digest their food in four stomach-like chambers as opposed to a single stomach. Pigs, on the other hand, are a good model because they digest food in a manner similar to that of humans. In addition to digestion and metabolism, factors such as cost and time must be considered. Pigs and other large animals are expensive to use, and they take a long time to develop nutrient deficiencies. Smaller laboratory animals, such as rats and mice, are therefore the most common experimental animals. They are inexpensive, have short life spans, reproduce quickly, and show the effects of nutritional changes rapidly. Their food intake can be easily controlled, and their excretions can be measured accurately using special cages. Even when researchers use small animals, the species of animal must be carefully chosen (Figure 1.18). For example, rats are more resistant to heart disease than are humans, so they are not a good model for studying the effect of diet on heart disease. Rabbits, on the other hand, do develop heart disease and can be used to study diet–heart disease relationships. Even the best animal model is not the same as a human, and care must be taken when extrapolating the results to the human population. For example, a study that uses rats to show that a calcium supplement increases bone density can hypothesize, but not conclude, that the supplement will have the same effect in humans.

Studies Using Cells Another alternative to conducting studies in humans is to study cells either extracted from humans or animals or grown in the laboratory (Figure 1.19). Biochemistry can be used to study how nutrients are used to provide energy and how they regulate biochemical reactions in cells. Molecular biology can be used to study how genes regulate cell functions and how nutrients affect the action of certain genes. Knowledge gained from biochemical and molecular biological research can be used to study nutrition-related conditions that affect the entire organism.



Lori Smolin

FIGURE 1.18 Choosing animals to model human nutrition
Guinea pigs are used to study vitamin C requirements and functions because the guinea pig is one of the few animals, other than humans, that cannot make vitamin C in its body.

Ethical Concerns in Scientific Study

Ethical issues are often raised in the process of conducting nutrition research. Whenever possible, researchers use alternatives to human subjects or experimental animals. However, when questions cannot be answered using alternatives such as cells grown in culture or computer models, human and animal experimentation are necessary. To avoid harm and protect the rights of humans and animals used in experimental research, government guidelines have been developed.

Before a study involving human subjects can be conducted, it must be reviewed by a committee of scientists and nonscientists to ensure that the

rights of the subjects are respected. The risk of physical, social, and psychological injury must be balanced against the potential benefit of the research. Before subjects participate in a study, oral and written explanations of the purpose of the research, the procedures used, and the possible risks and benefits are provided. Those who choose to participate must then sign a consent form stating exactly what they have agreed to do. Signing a consent doesn't mean subjects must complete the study if it turns out to be more than they bargained for—subjects can leave a study at any time. This informed consent process is part of the strict safety and ethical regulations that must be followed when research involves human subjects. These regulations protect subjects but limit the type of study that can be done on humans. For example, much of what we know today about the effects of starvation in humans was determined during World War II by conducting depletion-repletion studies using conscientious objectors as experimental subjects. These subjects were monitored physically and psychologically while they were starved and then re-fed. These individuals experienced some level of suffering during the trials and risked longer-lasting physical and psychological harm. It is unlikely that this study would be approved if researchers wanted to repeat it today.

Keith Weller/Courtesy USDA

FIGURE 1.19 Cell culture
The ability to grow cells in the laboratory allows scientists to study nutrients without using whole organisms.

THINK CRITICALLY

What are the advantages and disadvantages of using cells grown in culture to study human nutrition?

As with experiments involving humans, the federal government mandates that panels of scientists review experiments that propose to use animals. These panels consider whether the need for animals is justified and whether all precautions will be taken to avoid pain and suffering. Animal housing and handling are strictly regulated, and a violation of these guidelines can result in closure of a research facility.

The development of the techniques of molecular biology has given rise to ethical issues regarding the manipulation of genes. Guidelines for manipulating genes have been developed and are discussed in the Focus on Biotechnology.

1.5 Evaluating Nutrition Information

LEARNING OBJECTIVES

- Discuss why individual testimonies are not considered reliable sources of information.
- Name three points to consider when evaluating the reliability of nutritional information.
- Discuss the components of a well-designed study including experimental controls, control groups, and placebos.

We are bombarded with nutrition information. Some of what we hear is accurate and based on science and some of it is incorrect or exaggerated to sell products or make news headlines more enticing: Oat bran lowers cholesterol, antioxidants prevent cancer, low-carb diets promote weight loss, vitamin C cures the common cold, vitamin E slows aging. Sifting through this information and distinguishing the useful from the useless can be overwhelming. Just as scientists use the scientific method to expand their understanding of the world around us, each of us can use an understanding of how science is done to evaluate nutrition claims by asking the questions discussed below and summarized in Table 1.1.

TABLE 1.1 Sorting Out Nutrition Information

Does It Make Sense?
• **Is it too outrageous to believe?** If it is, disregard it.
• **Does it pose a risk?** If it doesn't sound safe, don't do it.
What's the Source?
• **Is it selling something?** Many claims are made to sell products rather than present unbiased nutrition information.
• **Is it someone's opinion or personal story?** Anecdotal information can be applied only to the person telling the story.
• **Who can you believe?** Recommendations made by the government, universities, and nonprofit organizations are based on science and designed to provide information to improve health.
Is It Based on Good Science?
• **Is the study well controlled?** Have experimental controls been used so that each variable studied can be compared with a known situation?
• **Were participants and researchers blinded to the treatment?** If the subjects or researchers know which group is receiving treatment, their beliefs and biases may alter the outcome of the study.
• **Was the information interpreted accurately?** Compare news reports and advertisements to the information in peer-reviewed studies. Has the importance of the study been exaggerated to sell a product or make a headline more appealing? If the study was done in animals, can the results be applied to humans?
Has It Stood the Test of Time?
• **Is the study the first to support a particular finding?** If it is, wait before changing your diet based on the results.
• **Has the finding been shown repeatedly in different studies over a period of years?** If it has, it will become the basis of reliable nutrition recommendations.

©Hernera/Age Fotostock America, Inc.

FIGURE 1.20 What's behind the claims?
This hypothetical supplement advertisement illustrates the types of nutrition claims that consumers must be prepared to evaluate.

Does It Make Sense?

The first question to ask yourself when evaluating nutrition information is this: Does the claim being made make sense? Some claims, we know, are too outrageous to be true or safe. For example, the hypothetical advertisement for StayWell states that this product will make illness a thing of the past (Figure 1.20). This is certainly appealing, but it is hard to believe, and common sense should tell you that it is too good to be true. The claim that StayWell will reduce cold symptoms, however, is not so outrageous. Common sense can also help determine whether health and nutrition information poses a risk. For example, a report that recommends you take supplements providing 1000% of the recommended amount of a vitamin or mineral should be viewed skeptically because high levels can be toxic and are not found in nature.

What's the Source?

If the claim seems reasonable, look to see where it came from. Was it a personal testimony, a government recommendation, or advice from a health professional? Is it in a news story or an advertising promotion? Is it on television, in a magazine, or on a Web page?

Is It Selling Something? If a person or company will profit from the information presented, you should be wary. Information presented in newspapers and magazines and on television may be biased or exaggerated because it is designed to help sell magazines or boost ratings. Consider whether the claim is making a magazine cover or newspaper headline more

appealing. Claims that are part of an advertisement for a food product or dietary supplement should be viewed skeptically because advertisements are designed to increase product sales and the company stands to profit from your belief in that claim. For example, in an advertisement for a vitamin E supplement, a company may claim that vitamin E increases longevity even if the research supporting this claim was done in rats, not humans; used higher amounts of vitamin E than are provided by the supplement; and caused only a very small change in life span. Information on the Internet is also likely to be biased toward a product if it comes from a site where you can buy the product (.com sites).

Is It Someone's Opinion or Personal Story? Personal testimonies or opinions, referred to as anecdotal evidence, are not a source of reliable information that can be applied to the general public (Figure 1.21). Reliable information comes from scientific experiments providing measurable data that can be quantified and repeated. Measurements of body weight and blood pressure are examples of parameters that can be quantified reliably. In contrast, the claims in Figure 1.20 that StayWell improves energy levels and overall sense of health and well-being are anecdotes based on the individual experiences of supplement users rather than on measured parameters. To be useful in science, feelings and opinions must be quantified using standardized questionnaires.

Who Can You Believe? There are a number of sources you can rely on for credible nutrition information. Government recommendations regarding healthy dietary practices are developed by committees of scientists who interpret the latest well-conducted research studies and use their conclusions to develop recommendations for the population as a whole. The government provides information about food safety and recommendations on food choices and the amounts of specific nutrients needed to promote health and avoid nutrient deficiencies and excesses. These recommendations are the basis for public health policies and programs. They are published in pamphlets and brochures and are available on websites designed for consumers. Government recommendations are also used to develop food labeling standards (see **Off the Label: Beware of Misleading Claims**).

Nonprofit organizations such as the Academy of Nutrition and Dietetics, the American Medical Association, and the American Institute for Cancer Research are also good sources of nutrition information. The purpose of the information they provide to the public is to improve health. Reports that come from universities are supported by research and are also a reliable place to look for information. Many universities provide information that targets the general public, and university research studies are usually published in respected journals and are well scrutinized.

To help you evaluate the credibility of information in an article in print or posted on a website, check the author's credentials. Where does the author work? Does this person have a degree in nutrition or medicine? Although "nutritionists" and "nutrition counselors" may provide accurate information, these terms are not legally defined and are used by a wide range of people, from college professors with doctoral degrees from reputable universities to health-food-store clerks with no formal training.

One reliable source of nutrition information is a registered dietitian or registered dietitian nutritionist (RD/ RDN). RD/RDNs are nutrition professionals who are certified to provide nutrition education and counseling. To obtain certification, an RD/RDN must earn a four-year college degree that includes coursework approved by the Academy of Nutrition and Dietetics, complete a supervised internship, and pass a national exam.

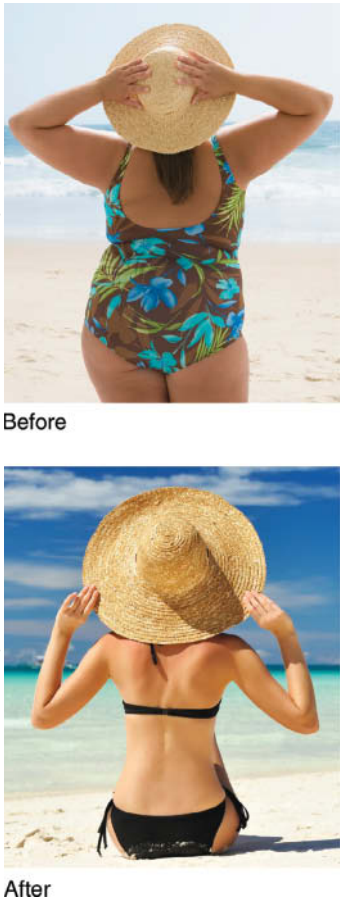


FIGURE 1.21 Anecdotal claims Weight-loss product advertisements often show before and after photos of people who have successfully lost weight using the product. These photos and personal stories of success are anecdotal evidence because they do not arise from controlled experiments that are evaluated scientifically. Therefore, it cannot be assumed that the product will produce the same results for you or anyone else.

Is It Based on Good Science?

Most of the information we get is based on research studies. For some nutrition claims, not enough information is given to evaluate the validity of the studies on which they are based. Others, however, do provide the details of how a study was done. For example, the StayWell ad (see Figure 1.20) describes a university study that supposedly supports the advertiser's claims. If this type of information is available, ask yourself if the study was well controlled and if the results were interpreted accurately.

OFF THE LABEL

Beware of Misleading Claims

© iStockphoto

Food labels are designed to provide information that can help you select a healthy diet, but manufacturers also use this information to help sell their products. Although labels are standardized and follow Food and Drug Administration (FDA) guidelines, some of the information can still be confusing and even misleading. You need to consider all the information on the label and remember that each food choice is only one part of your overall diet.

Many food labels highlight information about the amounts of individual nutrients or ingredients. Food manufacturers use these to draw attention to the positive aspects of their products or distract you from the health negatives. For example, a breakfast cereal labeled "made with whole grain" sounds like a healthy choice, but it may contain only a small amount of whole grain and be loaded with added sugar. The claim that a snack is "made with real fruit" would cause most people to choose it over one that does not make this claim. Unfortunately, since the FDA does not dictate how much real fruit a product must contain to make this claim, these products may not contain very much fruit at all. A granola bar with a single dried cranberry could make this claim.

Manufacturers also use more general descriptors such as "natural," "fresh," and "healthy," to imply that a product is healthier than a similar alternative. This is not necessarily the case. The FDA only restricts the use of the term "natural" on foods that contain added colors, artificial flavors, or synthetic substances. So, a food that has sugar or salt added to it can still claim to be "natural." The term "fresh" can be used on any raw food that has not been frozen, heat processed, or otherwise preserved. The term doesn't provide any information about the nutrient content of the food or how long it took the product to travel from the farm to the grocery store shelf. "Healthy" implies that a product is wholesome and nutritious. In fact, to use the term "healthy," a food must be low in fat and saturated fat, contain no more than 360 mg of sodium and 60 mg of cholesterol per serving, and be a good source of one or more important nutrients. Although all these qualities are indeed part of a healthy diet, foods that fit this definition are not necessarily the basis for a healthy diet. For instance, many fruit drinks fit the labeling definition of healthy. They are low in fat, saturated fat, cholesterol, and sodium, and they supply at least 10% of the recommended intake for vitamin C. But they are a good choice only in limited quantities because they are high in added refined sugars. Likewise, a food that doesn't meet the labeling definition of healthy is not necessarily a poor choice. Vegetable soup, for example, contains more sodium than the definition of healthy will allow, but if the rest of your diet is not high in sodium, the soup can be a healthy choice.

Healthy-sounding product names can also be misleading. Product names must comply with legal definitions, but they don't have to make sense to consumers. Unless you have memorized the U.S. Department of Agriculture (USDA) and FDA regulations, you have no way of knowing how much beef is needed for a product to be called a beef enchilada, for example, or how much chicken must be in chicken soup and how much fruit is in a fruit roll-up. "Lasagna with meat sauce" must be 6% meat, but "lasagna with meat and sauce" must be 12% meat.

Remember that no single nutrient makes a food good or bad for you. To understand the overall contribution that a food makes to your diet, you need to look beyond the healthy-sounding descriptors and the product name. Read the whole label, which must include the food's nutrient content and information on how it fits into the diet as a whole (see Chapter 2 and the *Off the Label* boxes throughout this book).

Ken Karp

The claims made on food labels highlight one characteristic of the food. To get the whole picture, you need to read the rest of the label.

Is the Study Well Controlled? Experimental controls are used to ensure that each factor or **variable** studied can be compared with a known situation. A control group acts as a standard of comparison for the treatment being tested. A control group is treated in the same way as the experimental groups except no experimental treatment is implemented. For example, the university study described in the StayWell ad compares the severity of cold symptoms and the cold recovery time of college students who took the StayWell supplement (experimental group) with the same parameters in a group of students of similar age, gender, health status, and dietary and exercise habits who did not take the supplement (control group).

variable A factor or condition that is changed in an experimental setting.

In the StayWell experiment, a **placebo** was used in order to make the control and experimental groups indistinguishable. A placebo is identical in appearance to the actual treatment but has no therapeutic value. Using a placebo prevents participants in the experiment from knowing whether or not they are receiving the actual supplement. When the subjects do not know which treatment they are receiving, the study is called a **single-blind study**. Using a placebo in a single-blind study helps to prevent the expectations of subjects from biasing the results. For example, if the students think they are taking a supplement that reduces cold symptoms, they may develop a positive outlook that makes their cold symptoms milder. Errors can also occur if investigators' expectations bias the results or the interpretation of the data. This type of error can be avoided by designing a **double-blind study** in which neither the subjects nor the investigators know who is in which group until after the results have been analyzed.

placebo A fake medicine or supplement that is indistinguishable in appearance from the real thing. It is used to disguise the control and experimental groups in an experiment.

single-blind study An experiment in which either the study participants or the researchers are unaware of which participants are in a control or an experimental group.

double-blind study An experiment in which neither the study participants nor the researchers know which participants are in a control or an experimental group.

Was the Information Interpreted Accurately? In science, the interpretation of results is as important as the way studies are conducted. Even well-designed, carefully executed experiments can be a source of misinformation if the experimental results are interpreted incorrectly or if the implications of the results are exaggerated. For example, the headline in Figure 1.20 states that StayWell improves overall health. However, the study cited investigates only cold symptoms; overall health is not addressed. Also, StayWell is tested using college students as experimental subjects, so an accurate interpretation of the results would not assume that StayWell would have the same effect in elderly people or young children.

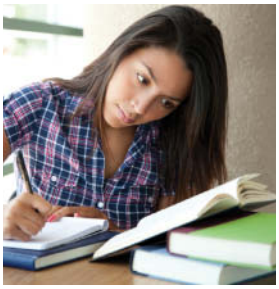
One way to ensure that experiments are correctly interpreted is to use a peer-review system. Most scientific journals require that prior to publication, two or three experts (who did not take part in the research that is being evaluated) agree that the experiment under review was well conducted and that the results were interpreted fairly. For example, reviewers will assess whether or not the study included enough subjects to demonstrate the effect of the experimental treatment. To claim a treatment has a particular effect, an experiment must show that the treatment being tested causes a result to occur more frequently than it would occur by chance. More subjects are needed to demonstrate an effect that frequently occurs by chance. For example, if many people only have mild symptoms when they get a cold, then an experiment to see if StayWell reduces cold symptoms would need to include many subjects to demonstrate an effect. However, if everyone got very ill with a cold, only a few subjects would be needed to show that StayWell reduces cold symptoms.

Peer-reviewed journals that publish nutrition-related articles include the *American Journal of Clinical Nutrition*, the *Journal of Nutrition*, the *Journal of the Academy of Nutrition and Dietetics*, the *New England Journal of Medicine*, and the *International Journal of Sport Nutrition and Exercise Metabolism*.

Has It Stood the Test of Time?

Often the results of a new scientific study are in the morning news the same day they are published in a peer-reviewed journal. Sometimes this information is correct, but a single study is never enough to develop a reliable theory. Results need to be reproducible before they can be used as the basis for nutrition decisions or used to make dietary recommendations. Headlines based on a single study should therefore be viewed skeptically. The information may be accurate, but there is no way to know because there has not been time to repeat the work and reaffirm the conclusions. If, for example, someone has found the secret to easy weight loss, the information will undoubtedly appear again if the finding is valid. If it is not, it will fade away with all the other weight-loss cures that have come and gone.

OUTCOME



Kaitlyn found it hard to eat a healthy diet during the first semester of her freshman year. At home, her favorite meal of a burger and fries was an occasional treat. Having this available every night made it hard for her to vary her diet. She knew this meal wasn't a great everyday choice, but she didn't know how to choose a healthy diet. After reading this chapter, Kaitlyn knows that a healthy diet includes a variety of foods. She now aims to eat an assortment of choices from within each of the food groups. She also recognizes that eating a healthy diet involves using moderation, so she doesn't consume too much of any one food or food group. She chooses a variety of fresh vegetables from the salad bar and tries different hot entrees each night. She makes a point of getting to the store where she can buy yogurt and fruit to keep in her dorm refrigerator. Kaitlyn now knows how to balance less healthy choices, like study snacks, with healthier foods at other times of the day. She is gaining confidence in her ability to balance her food intake with her activity. In addition, her understanding of the scientific method and how to evaluate nutrition information has given her the tools she needs to make decisions about following fads and using dietary supplements. **Now, in the middle of her second semester, Kaitlyn is maintaining her weight and using the principles of variety, balance, and moderation to choose a nutrient-dense diet that minimizes her risks of developing heart disease and high blood pressure.**

SUMMARY

1.1 Nutrition, Food Choices, and the American Diet

- Nutrition is a science that encompasses all the interactions that occur between living organisms and food. Nutrients are substances in foods that provide energy and structure and help regulate body processes.
- Food choices are affected by food availability, family and cultural traditions, emotional factors, and personal tastes and convictions. No one food choice is good or bad, and no one choice can make a diet healthy or unhealthy—each choice contributes to the diet as a whole.
- In 21st-century America, we spend less time preparing food and eating at home and rely more on processed convenience foods and food prepared away from home than we did 50 years ago.
- Americans eat more calories than they did 50 years ago, primarily due to larger portion sizes and more snacking. The typical American diet does not meet the recommendations for a healthy diet and contributes to the development of chronic diseases such as diabetes, obesity, and heart disease.

1.2 Food Provides Nutrients

- About 45 nutrients are essential to human life. Nutrients consumed come from those naturally present in foods, those added to fortified foods, and those contained in dietary supplements. In addition to nutrients, food provides phytochemicals and zoochemicals, nonessential substances that may provide health benefits.
- There are six classes of nutrients: carbohydrates, lipids, proteins, water, vitamins, and minerals. Carbohydrates, lipids, and proteins are energy-yielding nutrients. The energy they provide to the body is measured in kilocalories or kilojoules. Carbohydrates, lipids, protein, water, and minerals provide structure to the body, and all nutrient classes help regulate the biochemical reactions of metabolism to maintain homeostasis.
- Nutrients provide energy, structure, and regulation and are needed by the body for growth, maintenance and repair, and reproduction.

1.3 Nutrition and Health

- When energy or one or more nutrients are deficient or excessive in the diet, malnutrition may result. Malnutrition includes both undernutrition and overnutrition. Depending on the cause, the symptoms of malnutrition can occur in the short term or over the course of many weeks, months, or even years.
- Undernutrition is caused by a deficiency of energy or nutrients. Overnutrition may be caused by a toxic dose of a nutrient or the chronic overconsumption of energy or of nutrients that increases the risk of chronic disease.
- Our health is affected both by our diet and our genetic makeup. The genes a person inherits affect the impact their diet has on their health, and the nutrients and other food components they consume affect the activity of their genes.
- A healthy diet includes a variety of nutrient-dense foods from each food group as well as a variety of foods from within each group. It balances energy and nutrient intake with needs and moderates choices to keep intakes of energy, fat, sugar, sodium, and alcohol within reason.

1.4 The Science Behind Nutrition

- The science of nutrition uses the scientific method to determine the relationships between food and the nutrient needs and health of the body. The scientific method involves making observations of natural events, formulating hypotheses to explain these events, designing and performing experiments to test the hypotheses, and developing theories that explain the observed phenomena based on the experimental results.
- The science of nutrition uses many different types of experimental approaches to determine nutrient functions and requirements. Observational studies identify relationships between diet and health. Intervention trials can test hypotheses developed from epidemiology. Laboratory studies use biochemical and molecular methods to study whole organisms or cells.
- Ethical guidelines protect humans and animals involved in research studies but limit the types of experiments that can be done.

1.5 Evaluating Nutrition Information

- When judging nutrition claims, first consider whether the information makes sense and is safe and whether it comes from a reliable source, such as an educational institution, the government, or a nonprofit organization. Information that promotes a product or in any other way benefits the person or organization providing it should be viewed with skepticism. Individual testimonies cannot be trusted because they have not been tested by experimentation.
- To be valid, nutrition information should be based on experiments that use quantifiable measurements, the right type and number of experimental subjects, appropriate controls, and a careful interpretation of experimental results. Reliable information will be supported by more than a single research study.

CHAPTER OUTLINE

2.1 The Development of Nutrition Recommendations
Early U.S. Dietary Recommendations
A Shift in the Focus of Dietary Guidance

2.2 Dietary Reference Intakes
Recommendations for Nutrient Intake
Recommendations for Energy Intake
Applications of the Dietary Reference Intakes

2.3 The Dietary Guidelines for Americans
What Are the Dietary Guidelines?
Follow a Healthy Eating Pattern
Shift to Healthier Choices
Support from All Segments of Society

2.4 MyPlate: Putting the Dietary Guidelines into Practice
Understanding the MyPlate Messages
How to Use MyPlate

2.5 Food and Supplement Labels
Food Labels
Dietary Supplement Labels
Understanding Label Claims
What Must Be Labeled?

2.6 Other Nutrition Guidelines
The Healthy People Initiative
Choice (Exchange) Lists for Meal Planning
Recommendations from Special Interest Groups

2.7 Assessing Nutritional Health
How to Assess an Individual's Nutritional Status
How the Nutritional Health of a Population Is Assessed

(©iStockphoto)

© Spaces Images/SuperStock

Nutrition Guidelines: Applying the Science of Nutrition

2

CASE STUDY

Joe is starting college on an athletic scholarship. Although it is only September, he wants to make sure he eats well to be in shape for track season in March. Now that he is away from home and making his own food choices, Joe feels overwhelmed. Should breakfast be oatmeal, doughnuts, an omelet, or just fruit? He knows the burgers and fries he likes for lunch are not the best choice, but when he settles for the salad bar he gets hungry in the afternoon and eats junk food. The dinner choices are even more overwhelming—there is always some type of meat entree, a pasta dish, fish, and a vegetarian option. For dessert there are cakes, pies, and big vats of scoop-your-own ice cream. He notices that many of his friends pile their plates and take two or three desserts, but he knows that if he eats that way he will gain weight. His track coach has suggested that he talk to the team nutrition advisor, who is also a professor in the university's Department of Nutritional Sciences.

Joe is surprised when the professor suggests that he go to the MyPlate website to find out how to choose a healthy diet. Joe knows that there is a lot of nutrition information online, but he never knew what to trust. The MyPlate site gives him a picture of what his plate should look like when he gets through the cafeteria line. It also has plenty of other information that helps him figure out what to choose. With the MyPlate picture in his head, Joe finds it much easier to feel good about what he eats in the cafeteria. **He knows this is something he can follow and that it will help him to be ready for track in the spring.**

© Blend Images/SuperStock

2.1 The Development of Nutrition Recommendations

LEARNING OBJECTIVES

- List two reasons why population-wide nutrition recommendations are developed.
- Distinguish food guides from nutrient intake recommendations.
- Discuss how the focus of food guides has changed since the 1940s.

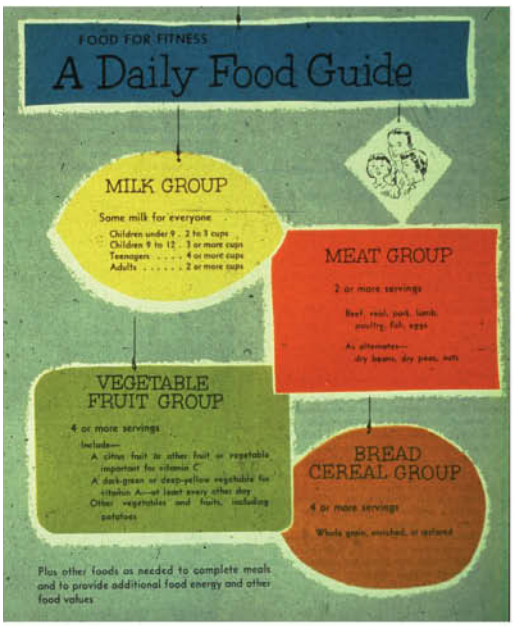
We need to eat to survive, but in order to have long, productive lives, we need to choose diets that will optimize our health. An optimal diet contains just the right amount of each nutrient to prevent deficiencies and maintain health and, for some people, to maintain a healthy pregnancy or to allow growth. The science of nutrition has determined which nutrients are necessary to keep humans alive and how much of each is needed at different stages of life. This information has been used to make recommendations for the types and amounts of nutrients and foods that will maintain the health of individuals and populations. These recommendations are also used as a standard of comparison to assess whether populations and individuals are consuming diets that promote health.

Early U.S. Dietary Recommendations

The U.S. government has been in the business of making nutritional recommendations for over 100 years. These recommendations have changed over time as our food intake patterns have changed and our knowledge of what constitutes a healthy diet has evolved.

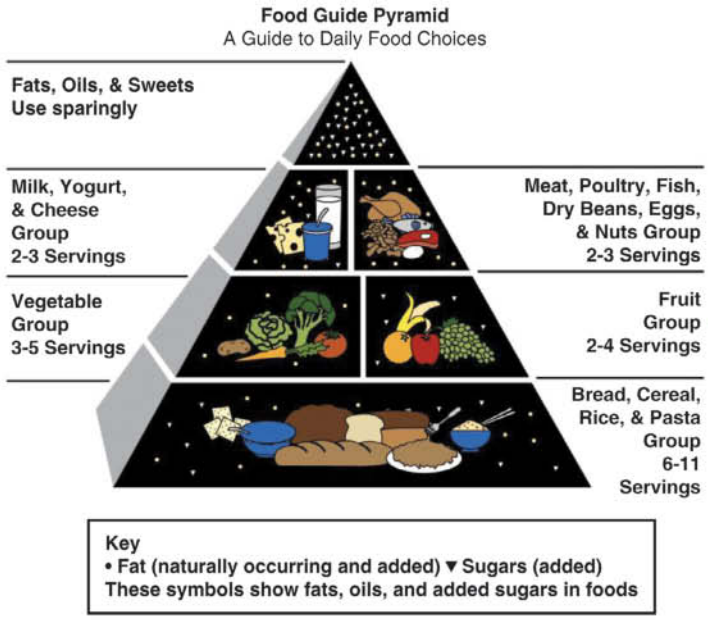
The first dietary recommendations in the United States were published in 1894 by the USDA. They suggested amounts of protein, carbohydrate, fat, and "mineral matter" needed to keep Americans healthy.[1] At the time, specific vitamins and minerals essential for health had not

FIGURE 2.1 A timeline of food guides
How food guides present recommendations has changed over the years, but the basic message has stayed the same: Choose the right combinations of foods to promote health.



1956

The Basic Four recommended a minimum number of foods from each of four food groups—milk, meat, vegetables and fruits, and bread and cereal—and focused on getting enough nutrients.



1992

The 1992 Food Guide Pyramid organized food groups into a pyramid shape to emphasize the relative contribution of each group—more should be consumed from the larger food groups at the bottom.

Courtesy USDA

been identified; nevertheless, this work set the stage for the development of food guides, which help people choose foods that make up a healthy diet. Over the years, the recommendations and presentation of food guides have evolved. In the 1940s, people were advised to follow a food guide with seven food groups called the "Basic Seven." In 1956, the seven were condensed to the "Basic Four." A guide with four food groups was used for the next two decades and eventually evolved into MyPlate, the current food guide (Figure 2.1).

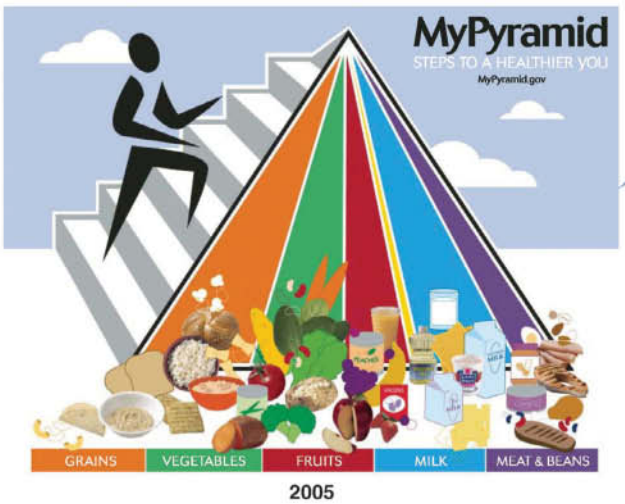
Other types of nutrition recommendations have also been developed and evolved over time (see **Debate: How Involved Should the Government Be in Your Food Choices?**). In the early 1940s, as the United States entered World War II, the Food and Nutrition Board was established to advise the army and other federal agencies regarding problems related to food and the nutritional health of the armed forces as well as the general population. They developed the first set of recommendations for specific amounts of nutrients; these came to be known as the Recommended Dietary Allowances (RDAs). These original RDAs made recommendations for amounts of energy and for nine essential nutrients that were most likely to be deficient in people's diets—protein, iron, calcium, vitamins A and D, thiamin, riboflavin, niacin, and vitamin C. Recommended intakes were based on amounts that would prevent nutrient deficiencies.[2]

A Shift in the Focus of Dietary Guidance

Over the years since the first food guides and the original RDAs were developed, dietary habits and disease patterns have changed. Overt nutrient deficiencies are now rare in the United States, but the incidence of nutrition-related chronic diseases, such as heart disease, diabetes, osteoporosis, and obesity, has increased. The importance of nutrition in the changing disease patterns was first acknowledged in 1977 when the Senate Select Committee on Nutrition and Human Needs released the *Dietary Goals for the United States*.[3] This was the first set of recommendations that considered health promotion, rather than just deficiency prevention. The *Dietary Goals* were subsequently modified and published as the *Dietary Guidelines for Americans* in 1980 by the USDA and the U.S. Department of Health and Human Services. Since then, they have been revised approximately every five years to reflect advances in science and our understanding of what constitutes a diet that promotes health. The current, eighth edition was released as the *Dietary Guidelines for Americans, 2015–2020*.[4]

Other dietary recommendations have also responded to these changes in diet and disease patterns. The original RDAs have been expanded into the **Dietary Reference Intakes**

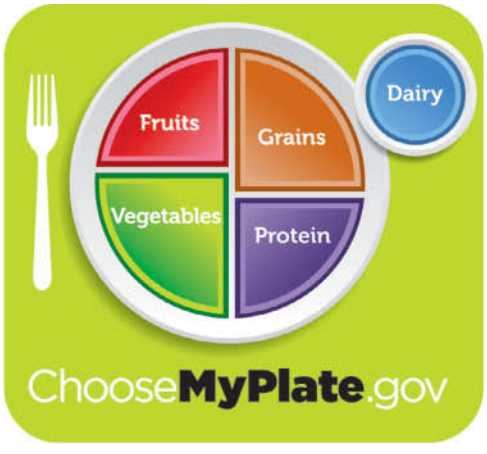
Dietary Reference Intakes (DRIs) A set of reference values for the intake of energy, nutrients, and food components that can be used for planning and assessing the diets of healthy people in the United States and Canada.



Courtesy USDA

2005

MyPyramid: Steps to a Healthier You kept the pyramid concept, but changed the shapes and arrangement of the food groups and added activity to the graphic.



Courtesy USDA

2011

MyPlate, shown here, was introduced in 2011 and is the latest food guide. It shows how much of your plate should be filled with various food groups.

DEBATE

How Involved Should the Government Be in Your Food Choices?

The typical U.S. diet is not as healthy as it could be. Poor dietary habits in the United States have resulted in an unfit, unhealthy nation. Our overindulgence has contributed to our high rates of obesity, diabetes, high blood pressure, and heart disease.[4] This is the concern not only of the individuals whose lives it affects but also of the government. The dollar cost to our health-care system is huge; half of the $147 billion per year the United States spends on obesity comes from government-funded Medicare and Medicaid.[5] Government concern is not just financial. The fact that almost one in four applicants to the military is rejected for being overweight is suggested as a threat to national security and military readiness.[6] So, who is responsible for our unhealthy diet, and who should be responsible for changing what we eat?

Joe Raedle/Getty Images

New York City officials tried unsuccessfully to prohibit restaurants, sports stadiums, movie theatres, and food carts from selling sugar-sweetened beverages larger than 16 oz.

Because of the financial and societal costs of an unfit nation, some argue that the government should be more involved in directing our dietary choices. Proponents of more government involvement in our food choices suggest that our food environment is the cause of our unhealthy eating habits. Obesity expert Kelly Brownell believes that environment plays a more powerful role in determining food choices than does personal irresponsibility.[7] Brownell and other proponents of government intervention argue that the government should treat our noxious food environment like any other public health threat and develop programs to keep us safe and healthy. Just as government regulations help to ensure that our food is not contaminated with harmful bacteria, laws could ensure that what you order at a restaurant will not contribute to heart disease or cancer. Unfortunately, unlike bacteria, individual foods are difficult to classify as healthy or unhealthy. Almost all food has some nutritional benefits, and arguments are ongoing as to what is a "junk food" and what we should add or subtract from our diets. However, many people believe there are things that could be done to ensure healthier choices.

One option to encourage healthier choices suggested by proponents of government intervention is to tax junk food, making it more expensive, and increase subsidies for fruits and vegetables, making them less expensive. Another is to control what can be sold. For example, in 2013 New York City's Board of Health attempted to prohibit the sale of sugar-sweetened drinks in cups larger than 16 ounces (oz) (see photo). The courts overturned the ban on the grounds that it exceeded the Board of Health's regulatory authority. Other suggestions to change the food environment include zoning restrictions to keep fast-food restaurants away from schools and limitations on the types of foods advertised on children's television. All these ideas have pros and cons, and none will absolve individuals of the responsibility for getting more exercise and making healthier food choices.

Opponents of government involvement believe such regulation is an infringement on personal freedom and suggest that individuals need to take responsibility for their actions. They propose that the food industry work with the public to make healthier food more available and affordable. Many food companies have already responded to the need for a better diet; General Mills and Kellogg's offer whole-grain cereals. And the giant food retailer Wal-Mart is working with suppliers to reduce the amount of sodium and added sugar and eliminate *trans* fat from packaged foods.

Our current food environment makes unhealthy eating easy. Opportunities for fatty, salty, and sweet foods are available 24/7, and the portions offered are often massive. To preserve our public health, the United States needs to change the way it eats. This change could be driven by government regulations and taxes, it could come from changes in the food industry, or it could come from individuals taking more responsibility for their choices and their health. A synergy of policy intervention, industry cooperation, and personal efforts is likely needed to solve the crisis.

THINK CRITICALLY: Do you think restricting the size of sodas sold will help curb obesity? Why or why not?

(DRIs), which address concerns about excess as well as deficiency. Early food guides have evolved into MyPlate, which suggests amounts and types of food from five food groups to meet the recommendations of the Dietary Guidelines (see Figure 2.1). In addition, standardized food labels have been developed to help consumers choose foods that meet these recommendations.

2.2 Dietary Reference Intakes

LEARNING OBJECTIVES

- Describe the four types of nutrient intake recommendations included in the DRIs and explain the purpose of each.
- Name the five variables used to calculate the Estimated Energy Requirements.
- Explain two ways in which the Dietary Reference Intakes are used.

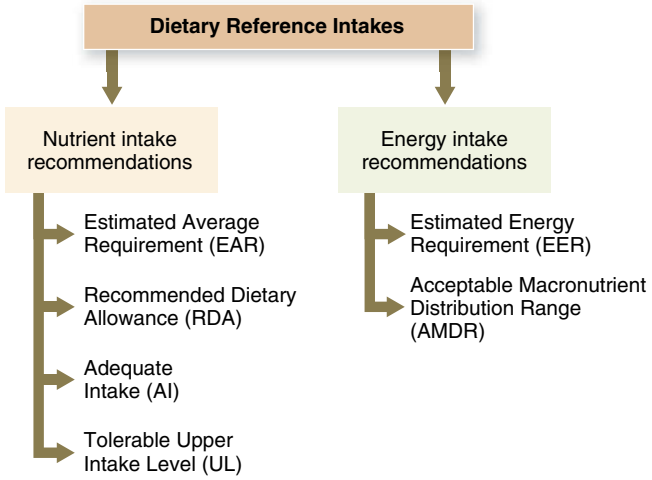
The Dietary Reference Intakes (DRIs) are recommendations for the amounts of energy, nutrients, and other food components that healthy people should consume in order to stay healthy, reduce the risk of chronic disease, and prevent deficiencies. They are not required amounts that must be consumed each day but recommendations for what should be consumed on an average daily basis. They include several types of recommendations that address both nutrient intake and energy intake and include values that are appropriate for people of different genders and stages of life. These values take into account the physiological differences that affect the nutrient needs of men and women, infants, children, adolescents, adults, older adults, and pregnant and lactating women (**Figure 2.2A**). The pregnancy and lactation recommendations are divided into age categories to distinguish the unique nutritional needs of pregnancy and lactation in teenagers and older mothers.

The DRI standards were developed for the United States and Canada. Different countries develop different standards based on the nutritional issues in their country. The World Health Organization and the Food and Agriculture Organization of the United Nations, organizations concerned with international health, publish a set of dietary standards to apply worldwide.[8]

FIGURE 2.2 DRI recommendations for all population groups

A. Because gender and life stage affect nutrient needs, DRI values have been set for each gender and all life stages.

© Christopher Futcher/iStockphoto



B. The DRIs include four types of nutrient intake recommendations and two types of recommendations related to energy intake.

Recommendations for Nutrient Intake

Estimated Average Requirements (EARs) Intakes that meet the estimated nutrient needs of 50% of individuals in a gender and life-stage group.

Recommended Dietary Allowances (RDAs) Intakes that are sufficient to meet the nutrient needs of almost all healthy people in a specific life-stage and gender group.

Adequate Intakes (AIs) Intakes that should be used as a goal when no RDA exists. These values are an approximation of the average nutrient intake that appears to sustain a desired indicator of health.

Tolerable Upper Intake Levels (ULs) Maximum daily intakes that are unlikely to pose a risk of adverse health effects to almost all individuals in the specified life-stage and gender group.

The DRI recommendations for macronutrients and micronutrients include four different sets of reference values (Figure 2.2B).[9] The **Estimated Average Requirements (EARs)** can be used to evaluate the nutrient intake of populations. The **Recommended Dietary Allowances (RDAs)** and the **Adequate Intakes (AIs)** can be used as goals for individual intake and to plan or evaluate individual diets, and the **Tolerable Upper Intake Levels (ULs)** recommend a limit above which nutrient toxicities are more likely.

Estimated Average Requirements (EARs)

An EAR is the amount of a nutrient that is estimated to meet the needs of 50% of people in the same gender and life-stage group (Figure 2.3). EAR values are useful for evaluating the adequacy of, and planning for, the nutrient intake of population groups. For example, the prevalence of low iron intake in a population can be estimated by looking at the proportion of the population with iron intakes below the EAR.

To set the EAR for a nutrient, scientists must establish a measurable indicator or criteria of adequacy for that nutrient. This may be the level of the nutrient or a metabolite of that nutrient in the blood, a body function that relies on the nutrient, or the appearance of a deficiency symptom. This functional indicator can then be evaluated to determine the biological effect of different levels of nutrient intake. Appropriate criteria of adequate intake must be established for each nutrient in each life-stage and gender group.

Recommended Dietary Allowances (RDAs)

The RDA values are higher than the EARs because they are calculated to meet the needs of nearly all healthy individuals in each gender and life-stage group. They are determined by starting with the EAR value and using the variability in the requirements among individuals to increase it to an amount that meets the needs of 97 to 98% of healthy individuals (see Figure 2.3). Because the RDA is set higher than the needs of most people, it serves as a target for individual intake. An intake less than the RDA does not necessarily indicate that the needs of that particular person have not been met; however, the risk of a deficiency is low if intake meets the RDA and increases as intake falls below the RDA.[10]

Adequate Intakes (AIs)

Although the AIs are also used as a guide for individual intake, they are not based on EAR values. AIs are estimates used when there is insufficient scientific evidence to set an EAR and calculate an RDA. The AIs are based on observed or experimentally

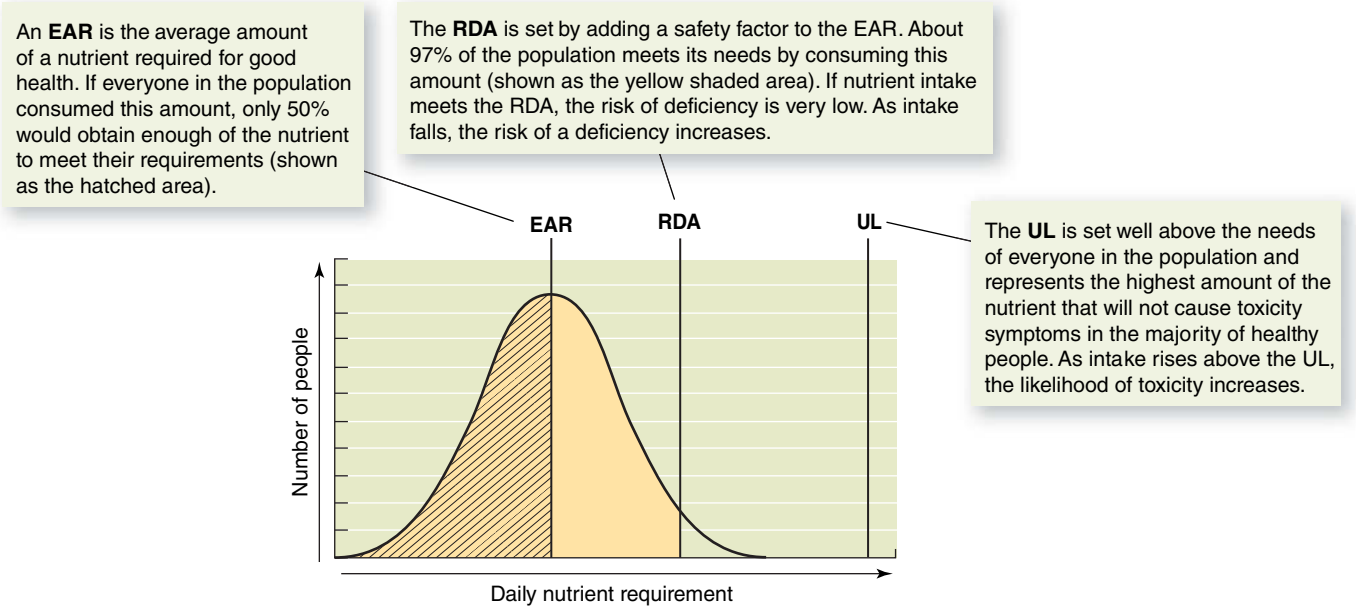


FIGURE 2.3 Understanding EARs, RDAs, and ULs
The EAR and RDA for a nutrient are determined by measuring the amount of the nutrient required by different individuals in a population group and plotting all the values. The resulting plot is a bell-shaped curve; a few individuals in the group need only a small amount of the nutrient, a few need a large amount, and the majority need an amount that falls between the extremes.

determined approximations of the average nutrient intake by a healthy population. When an AI value rather than an RDA is set, it targets the need for more research on the requirement for that nutrient. A healthy individual whose intake of a specific nutrient is at or above the AI is unlikely to be deficient in that nutrient.

Tolerable Upper Intake Levels (ULs) The fourth set of values, the Tolerable Upper Intake Levels, represents the maximum level of daily intake of a nutrient that is unlikely to pose a risk of adverse health effects to almost all individuals in the specified group. These are not recommended levels but rather levels of intake that can probably be tolerated (see Figure 2.3). ULs are used as a guide for limiting intake when people are planning diets and evaluating the possibility of overconsumption. The exact level of intake that will cause an adverse effect cannot be known with certainty for each individual, but if a person's intake is below the UL, there is good assurance that an adverse effect will not occur.

To establish a UL, a specific adverse effect or indicator of excess is considered. For instance, for niacin the ill effect is flushing, and for vitamin D it is elevated blood calcium levels. The lowest level of intake that causes the adverse effect is determined, and the UL is set far enough below this level that even the most sensitive people in the population are unlikely to be affected. If adverse effects have been associated only with intake from supplements, the UL is based only on this source. Therefore, for some nutrients these values represent intake from supplements alone; for some, intake from supplements and fortified foods; and for others, total intake from food, fortified food, water, nonfood sources, and supplements. For many nutrients, data are insufficient to establish a UL value.

Recommendations for Energy Intake

The DRIs make two types of recommendations regarding energy intake. One provides an estimate of how much energy is needed to maintain body weight, and the other provides information about the proportion of each of the energy-yielding nutrients from which this energy should come (see Figure 2.2B).

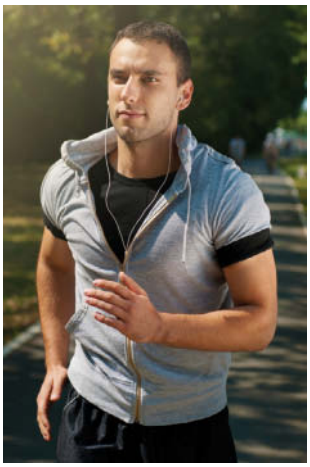
Estimated Energy Requirements (EERs) The recommendations for energy intake are called **Estimated Energy Requirements (EERs)**.[11] They provide an estimate of the number of calories needed to keep weight stable in a healthy person. Variables in the EER equations include age, gender, weight, height, and level of physical activity (see inside cover). Changing any of these variables changes the EER. For example, a 19-year-old girl who is 5 feet 4 inches tall and weighs 127 pounds (lb) and gets no exercise needs to eat 1940 kcalories (kcal) a day to maintain her weight. If she were taller or heavier, her energy needs would be greater. For example, if she were to gain 20 lb, her EER would increase to 2030 kcal/day; she would need to eat more to maintain her new weight. Increasing activity level also increases energy needs (Figure 2.4A). The EER calculations are discussed in more depth in Chapter 7.

Estimated Energy Requirements (EERs) Average energy intakes predicted to maintain body weight in healthy individuals.

Acceptable Macronutrient Distribution Ranges (AMDRs) The proportion of each of the energy-yielding nutrients in the diet is just as important as the total amount of energy consumed. Therefore, the DRIs make recommendations for the proportions of carbohydrate, fat, and protein that make up a healthy diet. These are called **Acceptable Macronutrient Distribution Ranges (AMDRs)**. These recommendations are expressed as ranges because healthy diets can be made up of many different proportions of carbohydrate, protein, and fat.[11] According to the AMDRs, a healthy diet for an adult can contain from 45 to 65% of calories from carbohydrate, 20 to 35% from fat, and 10 to 35% from protein. When calorie intake stays the same, changing the proportion of one of these will change the proportion of the others as well. So, for example, in a diet that provides 2000 kcal with 50% from carbohydrate, the other 50% will come from protein and fat. If the calories are kept the same but carbohydrate intake is decreased, the percentage of fat and/or protein will increase (Figure 2.4B). The AMDRs allow flexibility in food choices based on individual preferences while still providing a diet that minimizes disease risk. AMDR values have also been set for specific amino acids and fatty acids (see inside cover and Appendix A).

Acceptable Macronutrient Distribution Ranges (AMDRs) Ranges of intake for energy-yielding nutrients, expressed as a percentage of total energy intake, that are associated with reduced risk of chronic disease while providing adequate intakes of essential nutrients.

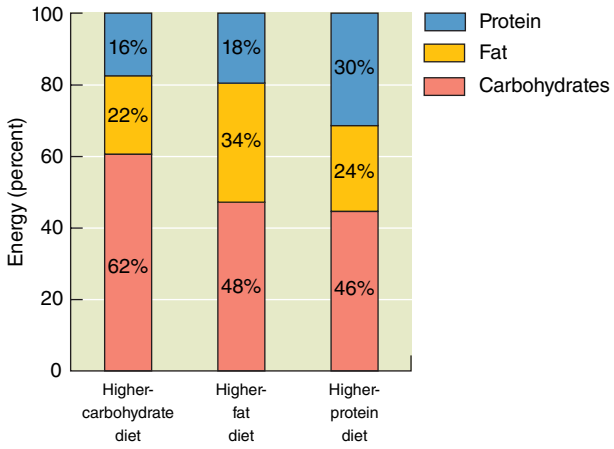
FIGURE 2.4 Energy intake: EERs and AMDRs



© Geber86/iStockphoto

A. This 20-year-old male is 6 feet tall and weighs 165 lb. If he jogs for 30 minutes five days a week he needs to consume 3196 kcal/day to maintain his weight. If he joins the track team and practices for several hours a day, he will need to up his intake to 3698 kcal/day or more to maintain his weight.

B. When energy intake remains constant, changing the amount of one of the energy-yielding nutrients in the diet changes the proportions of the others. All three of the combinations shown here fit within the AMDRs.



Applications of the Dietary Reference Intakes

The DRIs can be used to plan diets, to assess the adequacy of diets, and to make judgments about excessive intakes for individuals and populations.[9] For example, they can be used as a standard for meals prepared for schools, hospitals, and other health-care facilities; for government feeding programs for the elderly; and even for meals for astronauts. They can be used to determine standards for food labeling and to develop practical tools for diet planning, such as food guides. They can also be used to interpret information gathered about the food consumed by a population to help identify potential nutritional inadequacies that may be of public health concern.

Despite their many uses, dietary standards cannot be used to identify with certainty whether a specific person has a nutritional deficiency or excess. To ascertain this, an evaluation of the person's nutritional status using dietary, clinical, biochemical, and body-size measurements is needed, as discussed later in this chapter.

2.3 The Dietary Guidelines for Americans, 2015–2020

LEARNING OBJECTIVES

- Explain the purpose of the Dietary Guidelines.
- List four characteristics of a healthy eating pattern.
- Name three foods or food components that the Dietary Guidelines recommend we increase and three that we should decrease in our diets.
- Describe how all segments of society can be involved in promoting a healthy lifestyle.

What Are the Dietary Guidelines?

Unlike the DRIs, which provide recommendations for specific amounts of nutrients and food components, the Dietary Guidelines recommend overall diet and lifestyle choices that will promote health. The *2015–2020 Dietary Guidelines for Americans* include five overarching

TABLE 2.1 Dietary Guidelines for Americans, 2015–2020[4]

The Guidelines
1. **Follow a healthy eating pattern across the lifespan.** All food and beverage choices matter. Choose a healthy eating pattern at an appropriate calorie level to help achieve and maintain a healthy body weight, support nutrient adequacy, and reduce the risk of chronic disease.
2. **Focus on variety, nutrient density, and amount.** To meet nutrient needs within calorie limits, choose a variety of nutrient-dense foods across and within all food groups in recommended amounts.
3. **Limit calories from added sugars and saturated fats and reduce sodium intake.** Consume an eating pattern low in added sugars, saturated fats, and sodium. Cut back on foods and beverages higher in these components to amounts that fit within healthy eating patterns.
4. **Shift to healthier food and beverage choices.** Choose nutrient-dense foods and beverages across and within all food groups in place of less healthy choices. Consider cultural and personal preferences to make these shifts easier to accomplish and maintain.
5. **Support healthy eating patterns for all.** Everyone has a role in helping to create and support healthy eating patterns in multiple settings nationwide, from home to school to work to communities.
Key Recommendations
The *Dietary Guidelines'* Key Recommendations for healthy eating patterns should be applied in their entirety, given the interconnected relationship that each dietary component can have with others.
Consume a healthy eating pattern that accounts for all foods and beverages within an appropriate calorie level.
A healthy eating pattern includes
• A variety of vegetables from all of the subgroups—dark green, red and orange, legumes (beans and peas), starchy, and other
• Fruits, especially whole fruits
• Grains, at least half of which are whole grains
• Fat-free or low-fat dairy, including milk, yogurt, cheese, and/or fortified soy beverages
• A variety of protein foods, including seafood, lean meats and poultry, eggs, legumes (beans and peas), and nuts, seeds, and soy products
• Oils
A healthy eating pattern limits
• Saturated fats and *trans* fats, added sugars, and sodium
Key Recommendations that are quantitative are provided for several components of the diet that should be limited. These components are of particular public health concern in the United States, and the specified limits can help individuals achieve healthy eating patterns within calorie limits:
• Consume less than 10 percent of calories per day from added sugars
• Consume less than 10 percent of calories per day from saturated fats
• Consume less than 2,300 milligrams (mg) per day of sodium
• If alcohol is consumed, it should be consumed in moderation—up to one drink per day for women and up to two drinks per day for men—and only by adults of legal drinking age.
In tandem with the recommendations above, Americans of all ages—children, adolescents, adults, and older adults—should meet the *Physical Activity Guidelines for Americans* to help promote health and reduce the risk of chronic disease. Americans should aim to achieve and maintain a healthy body weight. The relationship between diet and physical activity contributes to calorie balance and managing body weight. As such, the *Dietary Guidelines* includes a Key Recommendation to
• Meet the *Physical Activity Guidelines for Americans*[a]

[a]U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans*. Washington (DC): U.S. Department of Health and Human Services; 2008. ODPHP Publication No. U0036. Available at: http://www.health.gov/paguidelines. Accessed January 15, 2016.

evidence-based guidelines that encourage healthy eating patterns, recognize that most Americans need to make shifts in their food and beverage choices to achieve a healthy pattern, and urge all segments of society to play a role in supporting healthy eating and activity choices.[4] Table 2.1 lists the five guidelines and the key recommendations of the 2015–2020 Dietary Guidelines. Adopting these recommendations will help support a healthy body weight, meet nutrient needs, and reduce the risk of chronic disease throughout all stages of life. The guidelines target Americans 2 years of age and older.

Follow a Healthy Eating Pattern

An eating pattern, also called a *dietary pattern*, is the combination of foods and beverages that make up an individual's intake over time. In recommending dietary patterns, the Dietary Guidelines recognize that a dietary pattern has a greater potential for promoting overall health than any individual food component in isolation. The components of an eating pattern can have interactive and potentially cumulative effects on health.

Healthy eating patterns provide an adaptable framework within which individuals can enjoy foods that meet their personal and sociocultural preferences and fit within their budgets. Patterns recommended by the guidelines include the USDA Food Patterns, which reflect the U.S.-style eating pattern, as well as a Mediterranean-Style Eating Pattern, Vegetarian Patterns, and the DASH Eating Plan (Figure 2.5). Each of these patterns is abundant in vegetables, fruits,

FIGURE 2.5 Healthy eating patterns
The Dietary Guidelines for Americans suggest that there are many ways to choose a healthy diet. Healthy dietary patterns all focus on similar types of foods, but choices can be tailored to suit an individual's preferences and meet their medical needs (see Appendices B and C for more information).

The DASH Eating Plan

Food group	Servings
Grains	6–8/day
Vegetables	4–5/day
Fruits	4–5/day
Fat-free or low-fat milk and milk products	2–3/day
Lean meats, poultry, and fish	6 or less/day
Nuts, seeds, and legumes	4–5/week
Fat and oils	2–3/day
Sweets and added sugars	5 or less/week

The DASH Eating Plan is plentiful in fruits and vegetables, whole grains, low-fat dairy products, fish, poultry, seeds, and nuts. It was first developed for lowering blood pressure (see Chapter 10).

USDA Food Patterns

Food group	Amount/day
Vegetables	2.5 cups
Fruit and juices	2.0 cups
Grains	6.0 ounces
Dairy products	3.0 cups
Protein foods	5.5 ounces
Oils	27 grams
Solid fats	16 grams
Added sugars	32 grams

Mediterranean Eating Pattern

Foods	How often
Fruits, vegetables, grains (mostly whole), olive oil, nuts, legumes and seeds, herbs and spices	Every meal
Fish and seafood	At least twice a week
Cheese and yogurt	Moderate portions daily or weekly
Poultry and eggs	Moderate portions every 2 days or weekly
Meats and sweets	Less often

Traditional Mediterranean eating patterns are based on fruits, vegetables, grains, olive oil, fish, beans, nuts, legumes, and seeds. They include smaller amounts of red meat and sweets. The incidence of chronic diseases such as heart disease is low in populations consuming these diets (see Chapter 5).

USDA Vegetarian Adaptations

Food group	Amount/day	
	Lacto-Ovo	Vegan
Dairy products or dairy substitutes	3 cups milk, calcium fortified soymilk, or yogurt, 4½ oz. hard cheese	3 cups calcium fortified soymilk or other plant-based milks or yogurts
Protein foods		
Eggs	4 per week	
Beans and Peas	⅓ cup	½ cup
Soy products	½ cup tofu, 2 oz. tempeh, ½ cup soybeans	½ cup tofu, 2 oz. tempeh, ½ cup soybeans
Nuts and Seeds	¼ cup	¼ cup

The USDA Food Patterns and their vegetarian adaptations suggest amounts of foods from different food groups for different calorie levels (2000 kcal shown here). These were developed to help individuals follow the Dietary Guidelines and are the basis for the MyPlate recommendations.

and whole grains; includes a variety of lean protein sources and nutrient-dense dairy foods; and emphasizes oils over solid fats. Each also limits added sugars, saturated and *trans* fats, sodium, and alcohol.

Shift to Healthier Choices

The Dietary Guidelines suggest that most Americans do not consume a healthy dietary pattern. To meet current recommendations for a nutrient-dense diet, most people need to shift food choices both within and across food groups. These shifts can occur slowly, beginning with small changes over the course of a week, a day, or even an individual meal (see **How to Choose: A Diet That Follows the Dietary Guidelines**).

Shift to Balance Calories with Activity The Dietary Guidelines emphasize balancing the calories consumed in foods and beverages with the calories expended through physical activity in order to achieve and maintain a healthy weight (Figure 2.6). Weight maintenance requires consuming the same number of calories as you burn; this means that if you eat more, you need to be more active (see Chapter 7). Most Americans would benefit from increasing their physical activity to a minimum of 150 minutes of moderate-intensity activity each week, and from limiting their screen time and sedentary leisure activity. This, along with attention to portion sizes and a shift to more nutrient-dense choices from both foods and beverages, will promote a healthy weight.

Shift to Meet Food Group Recommendations Most Americans do not meet recommendations for the amounts and variety of food from the various food groups. Selecting more whole fruits and eating a variety of vegetables, especially dark-green and red and orange vegetables and beans and peas, and eating more whole grains will help align intake with recommendations. The guidelines also suggest that Americans increase their intake of fat-free or low-fat milk and milk products while limiting consumption of high-fat dairy products such as cheese. This pattern of fruit, vegetable, grain, and dairy consumption will increase our intake of potassium, dietary fiber, calcium, and vitamin D, which are nutrients of concern in American diets. Most Americans consume enough protein foods, but need to shift the types of foods to include more seafood along with a variety of other protein choices, such as lean meat, poultry, eggs, beans and peas, soy products, and unsalted nuts and seeds.

HOW TO CHOOSE | A Diet That Follows the Dietary Guidelines

Balance calories to manage weight

- If you eat a large lunch, choose a lighter dinner.
- Ate more than you wanted over the weekend? Walk an extra 1000 steps every day this week.
- Watch your snack calories, they add up quickly.
- Ride your bike to work, to class, or when running errands.

Choose more fruits, vegetables, legumes, and whole grains

- Have whole strawberries for dessert.
- Put raisins on your oatmeal.
- Make your sandwich on whole-grain bread.
- Snack on carrots and peppers.
- Add beans to your taco.

Limit added sugars, saturated fat, and sodium

- Have water instead of sugar-sweetened drinks to reduce your added sugars.
- Grill some salmon instead of a burger to reduce saturated fat.
- Skip the chips to keep your sodium intake under control.

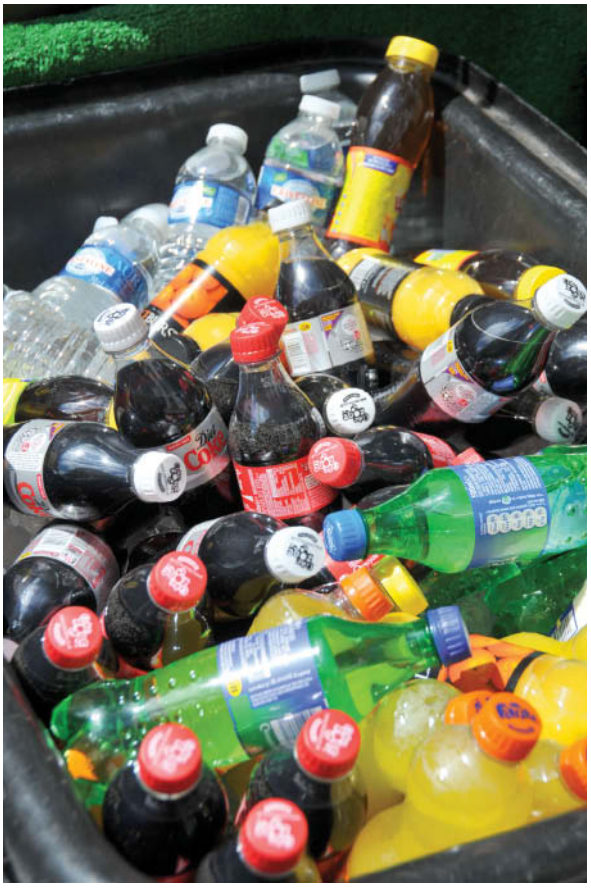
FIGURE 2.6 Healthy weight and exercise recommendations

Jose Luis Pelaez/Getty Images, Inc.

A. The Dietary Guidelines for Americans recommend choosing eating patterns that help maintain or achieve a healthy weight over time.

Alaska Stock Images/NG Image Collection

B. The Dietary Guidelines suggest that most Americans increase their aerobic physical activity gradually over time to a minimum of 150 min/week.



© Matthew Chattle/Alamy

FIGURE 2.7 The calories in your beverages count
Beverages contribute about 19% of our total energy intake and supply almost half of the added sugar in our diet.[12] The Dietary Guidelines recommend replacing sugar-sweetened drinks with water.

Shift to Limit Added Sugars, Saturated Fat, and Sodium The Dietary Guidelines set specific limits on the amounts of added sugars, saturated fat, and sodium that should be included in a healthy dietary pattern. They recommend that we reduce our intake of added sugars to less than 10% of calories (see Chapter 4). Currently, added sugars account for about 13% of our calorie intake; most of this comes from sweetened beverages such as soft drinks, fruit drinks, sweetened coffee and tea, and sport and energy drinks (Figure 2.7).[4] Too much saturated fat increases the risk of heart disease (see Chapter 5), yet only about one-third of Americans meet the recommendation to limit saturated fat to less than 10% of calories. The Dietary Guidelines recommend shifting to oils in place of solid fats to reduce saturated fat intake. The American diet is also too high in sodium. The Dietary Guidelines recommend limiting sodium intake to less than 2300 mg/day (see Chapter 10). This can be done by reducing reliance on packaged foods, which are the major source of sodium in our diets.

Support from All Segments of Society

Americans consume too many calories, don't meet food group and nutrient recommendations, and don't get enough physical activity. Changing this requires a new paradigm in which healthy lifestyle choices at home, at school, at work, and in the community are easy, accessible, and affordable. The 2015–2020 Dietary Guidelines suggest that changes at all levels of society can help individuals embrace and maintain healthy eating and physical activity patterns. Policy makers can implement strategies and programs that provide nutrition education and access to affordable, healthy food. Business and industry can modify products

and menus to align with the Dietary Guidelines. Communities can increase opportunities for physical activity by designing safe and accessible parks, recreation facilities, and sports programs. Individuals are encouraged to find their healthy eating and activity pattern by starting with small changes.

2.4 MyPlate: Putting the Dietary Guidelines into Practice

LEARNING OBJECTIVES

- Discuss the MyPlate recommendations for proportionality, variety, moderation, and nutrient density.
- Plan a diet based on the MyPlate recommendations.

To help individuals apply the recommendations of the Dietary Guidelines to their own food choices, the USDA has developed MyPlate (**Figure 2.8**).[14] This educational tool translates the Dietary Guidelines recommendations into the choices that make up a healthy dietary and lifestyle pattern. Like previous food guides, MyPlate is a food group system; it divides foods into groups based on the nutrients they supply most abundantly. The plate icon illustrates the proportions of food recommended from each of five food groups: fruits, vegetables, grains, protein foods, and dairy. Half of your plate should be fruits and vegetables, about a quarter grains, and about a quarter protein foods. Dairy should accompany meals, as shown by the glass to the side (see Figure 2.8A). The amounts recommended from each food group for an individual depend on that individual's energy needs.

Understanding the MyPlate Messages

MyPlate emphasizes the importance of proportionality, variety, moderation, and nutrient density in a healthy diet. Proportionality means eating more of some types of foods than others. The MyPlate icon shows the food groups in the proportions recommended in a healthy diet (see Figure 2.8A).

Variety is important for a healthy diet because no one food or food group provides all the nutrients and food components the body needs. A variety of foods should be selected from within each food group. The vegetables food group includes choices from five subgroups: dark-green vegetables such as broccoli, collard greens, and kale; red and orange vegetables such as carrots, sweet potatoes, and red peppers; starchy vegetables such as corn, green peas, and potatoes; other vegetables such as cabbage, asparagus, and artichokes; and beans and peas such as lentils, chickpeas, and black beans. Beans and peas are good sources of the nutrients found in both vegetables and protein foods, so they can be counted in either food group. Protein foods include meat, poultry, seafood, beans and peas, eggs, processed soy products, nuts, and seeds. Grains include whole grains such as whole-wheat bread, oatmeal, and brown rice as well as refined grains such as white bread, white rice, and white pasta (see Chapter 4). Fruits include fresh, canned, or dried fruit and 100% fruit juice. Dairy includes all fluid milk products and many foods made from milk such as cheese, yogurt, and pudding, as well as calcium-fortified soy products.

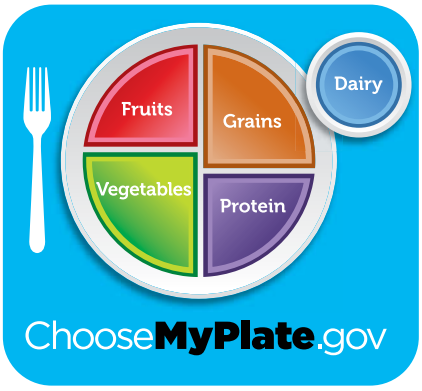
Moderation involves limiting portion sizes and choosing nutrient-dense foods to balance calories consumed with calories expended. Tips, designed to help consumers make nutrient-dense choices, such as make half your grains whole, choose whole fruits more often than juice, select fat-free or low-fat dairy products, and keep meat and poultry portions small and lean, can be found on the MyPlate website.

How to Use MyPlate

Your MyPlate Daily Checklist, previously known as your Daily Food Plan, tells you how much food to eat from each food group (see Figure 2.8B) and how much saturated fat, sodium,

FIGURE 2.8 MyPlate recommendations

A. The MyPlate icon shows what a balanced diet should look like. Shown here next to the icon are some key messages to help consumers balance calories and increase the nutrient density of their diet.



Balancing Calories

- Enjoy your food, but eat less.
- Avoid oversized portions.

Foods to Increase

- Make half your plate fruits and vegetables.
- Make at least half your grains whole grains.
- Switch to fat-free or low-fat (1%) milk.

Foods to Reduce

- Compare sodium in foods such as soup, breads, and frozen meals—and choose the foods with lower numbers.
- Drink water instead of sugary drinks.

Grains 6 ounces	Vegetables 2 1/2 cups	Fruits 2 cups	Dairy 3 cups	Protein 5 1/2 ounces
Make half your grains whole Aim for at least **3 ounces** of whole grains a day	**Vary your veggies** Aim for these amounts **each week:** **Dark-green veggies** = 1 1/2 cups **Red & orange veggies** = 5 1/2 cups **Beans & peas** = 1 1/2 cups **Starchy veggies** = 5 cups **Other veggies** = 4 cups	**Focus on fruits** Eat a variety of fruit Choose whole or cut-up fruits more often than fruit juice	**Get your calcium-rich foods** Drink fat-free or low-fat (1%) milk for the same amount of calcium and other nutrients as whole milk but less fat and Calories Select fat-free or low-fat yogurt and cheese, or try calcium-fortified soy products	**Go lean with protein** Twice a week, make seafood the protein on your plate Vary your protein routine–choose beans, peas, nuts, and seeds more often Keep meat and poultry portions small and lean

Find your balance between food and physical activity
Be physically active for at least **150 minutes** each week.

Know your limits on fats, sugars, and sodium
Your allowance for oils is **6 teaspoons** a day. Limit calories from solid fats and added sugars to **260 Calories** a day. Reduce sodium intake to less than **2300 mg** a day.

B. The MyPlate Daily Food Plan shown here is for a person who needs 2000 kcal/day. You can find your own food plan using the tables below, Appendix B, or the MyPlate Web site **www.ChooseMyPlate.gov**.

and added sugar can be included your diet without exceeding the recommended limits. The amounts from the grains group are expressed in ounces. An ounce of grains is equivalent to 1 cup of cold cereal, ½ cup of cooked cereal or grains, or a slice of bread. So if you have 2 cups of cereal and 2 slices of toast at breakfast, you have already consumed 4 oz of grains for the day (two-thirds of the total for a 2000-kcal diet). The amounts recommended for protein foods are also expressed in ounces. One ounce is equivalent to an ounce of cooked meat, poultry, or fish; one egg; 1 tablespoon (T) of peanut butter; ¼ cup of cooked dry beans; or ¼ cup of nuts or seeds. The amounts recommended for fruits, vegetables, and dairy are given in cups. Table 2.2 provides examples of amounts of foods that are equivalent to a cup of vegetables, fruits, or dairy, or an ounce of grains or protein foods.

TABLE 2.2 What Counts as an Ounce or a Cup?

Grains	One cup of rice is the size of a baseball	**Food**	**Amount that counts as an ounce**
		Bagel	¼ large or 1 mini bagel
		Bread	1 regular slice
		Crackers	5 whole wheat or 7 square or round
		Cooked cereal, rice, or pasta	½ cup (a typical serving size is 1 cup)
		Popcorn	3 cups, ¼ microwave bag
		Ready-to-eat breakfast cereal	1 cup flakes or rounds, 1¼ cup puffed
Vegetables	A medium potato is the size of a computer mouse	**Food**	**Amount that counts as a cup**
		Broccoli	1 cup chopped or 3 spears 5″ long
		Carrots	1 cup strips, 2 medium carrots, or 12 baby carrots
		Greens (collards, mustard greens, turnip greens, kale, spinach)	1 cup cooked
		Raw leafy greens (spinach, romaine, dark-green leafy lettuce, endive)	2 cups raw
		Sweet potato	1 large baked (2¼″ or more diameter)
		Corn on the cob	1 large ear (8 to 9″ long)
		Dry beans	1 cup cooked whole or mashed
		White potatoes	1 medium boiled or baked (2½ to 3″ diameter); french fried: 20 medium to long strips (2½ to 4″ long)
		Tomatoes	1 large whole (3″ diameter); 1 cup chopped raw, canned, or cooked; 1 cup juice
Fruits	A medium apple is the size of a baseball	**Food**	**Amount that counts as a cup**
		Apple	½ large or 1 small
		Banana	1 large (8 to 9″ long), 1 cup sliced
		Orange	1 large (3″ diameter)
		Strawberries	8 large
		Grapes	32 seedless grapes
		Dried fruit	½ cup
		100% fruit juice	1 cup
Dairy	An ounce of cheese is the size of four dice	**Food**	**Amount that counts as a cup**
		Milk and yogurt	1 cup
		Cheese	2 slices or 1½ oz hard cheese, ⅓ cup shredded, ½ cup ricotta, 2 cups cottage cheese
		Pudding or frozen yogurt	1 cup
		Ice cream	1½ cups or 3 scoops
Protein	Three ounces of meat or tofu is the size of a deck of cards	**Food**	**Amount that counts as 1 ounce**
		Meat, poultry, fish	1 oz cooked, ⅓ small steak, ⅓ small hamburger, ⅓ chicken breast, ⅓ can tuna (a typical serving size is 3 oz)
		Eggs	1 egg
		Nuts and seeds	½ oz, 12 almonds, 24 pistachios, 7 walnut halves
		Dry beans or peas	¼ cup cooked black, kidney, or pinto beans; ¼ cup cooked chick peas, lentils, or split peas; ½ cup lentil soup; ¼ cup tofu; 2 T hummus; 1 T peanut butter

TABLE 2.3 Estimated Energy Needs (kilocalories)

	Males			Females		
Age (yrs)	Inactive	Moderately active	Active	Inactive	Moderately active	Active
16–18	2400	2800	3200	1800	2000	2400
19–20	2600	2800	3000	2000	2200	2400
21–25	2400	2800	3000	2000	2200	2400
26–30	2400	2600	3000	1800	2000	2400
31–35	2400	2600	3000	1800	2000	2200
36–40	2400	2600	2800	1800	2000	2200
41–45	2200	2600	2800	1800	2000	2200
46–50	2200	2400	2800	1800	2000	2200
51–55	2200	2400	2800	1600	1800	2200
56–60	2200	2400	2600	1600	1800	2200
61–65	2000	2400	2600	1600	1800	2000
66–70	2000	2200	2600	1600	1800	2000

Inactive = less than 30 minutes a day of moderate activity.
Moderately active = between 30 and 60 minutes of moderate activity a day.
Active = 60 minutes or more of moderate activity a day.
Source: www.ChooseMyPlate.gov

TABLE 2.4 Food Group Amounts for Different Energy Levels

Energy level (kcal)	1800	2000	2200	2400	2600	2800	3000	3200
Grains (oz)	6	6	7	8	9	10	10	10
Vegetables (cups)	2.5	2.5	3	3	3.5	3.5	4	4
Fruits (cups)	1.5	2	2	2	2	2.5	2.5	2.5
Dairy (cups)	3	3	3	3	3	3	3	3
Protein (oz)	5	5.5	6	6.5	6.5	7	7	7
Oils (teaspoon)	5	6	6	7	8	8	10	11
Empty calorie allowance (kcal)	160	260	270	330	360	400	460	600

Source: www.ChooseMyPlate.gov

The calorie needs and recommended amounts from each food group for adults are summarized in Tables 2.3 and 2.4. To find your MyPlate Food Plan, look up your calorie needs in Table 2.3 and then match them to your recommended food group amounts in Table 2.4. Once you know how much to choose from each group, you can plan your meals and snacks for the day. Figure 2.9 shows a sample day's menu for a 2000-kcal diet.

It is easy to see where some foods in your diet fit on MyPlate. For example, a chicken breast is 3 oz from the protein group; a scoop of rice is 2 oz from the grains group. It is more difficult to see how much mixed foods such as pizza, stews, and casseroles contribute to each food group. To fit these on your plate, individual ingredients must be considered. For example, a slice of pizza provides 1 oz of grains, ⅛ cup of vegetables, and ½ cup of dairy. Having meat on your pizza adds about ¼ oz from the protein group (see Figure 2.9 and **Critical Thinking: Fitting Foods, Meals, and Diets onto MyPlate**).

MyPlate also includes recommendations about the amounts of oils (in teaspoons) that should be included in your diet (see Figures 2.8B and 2.9). Oils are fats that are liquid at room temperature; they come from plants and fish. They are rich in unsaturated fats, which help protect against heart disease. Solid fats are fats that are solid at room temperature, such as butter, lard, and shortening. They provide saturated and *trans* fat and should be limited in the diet.

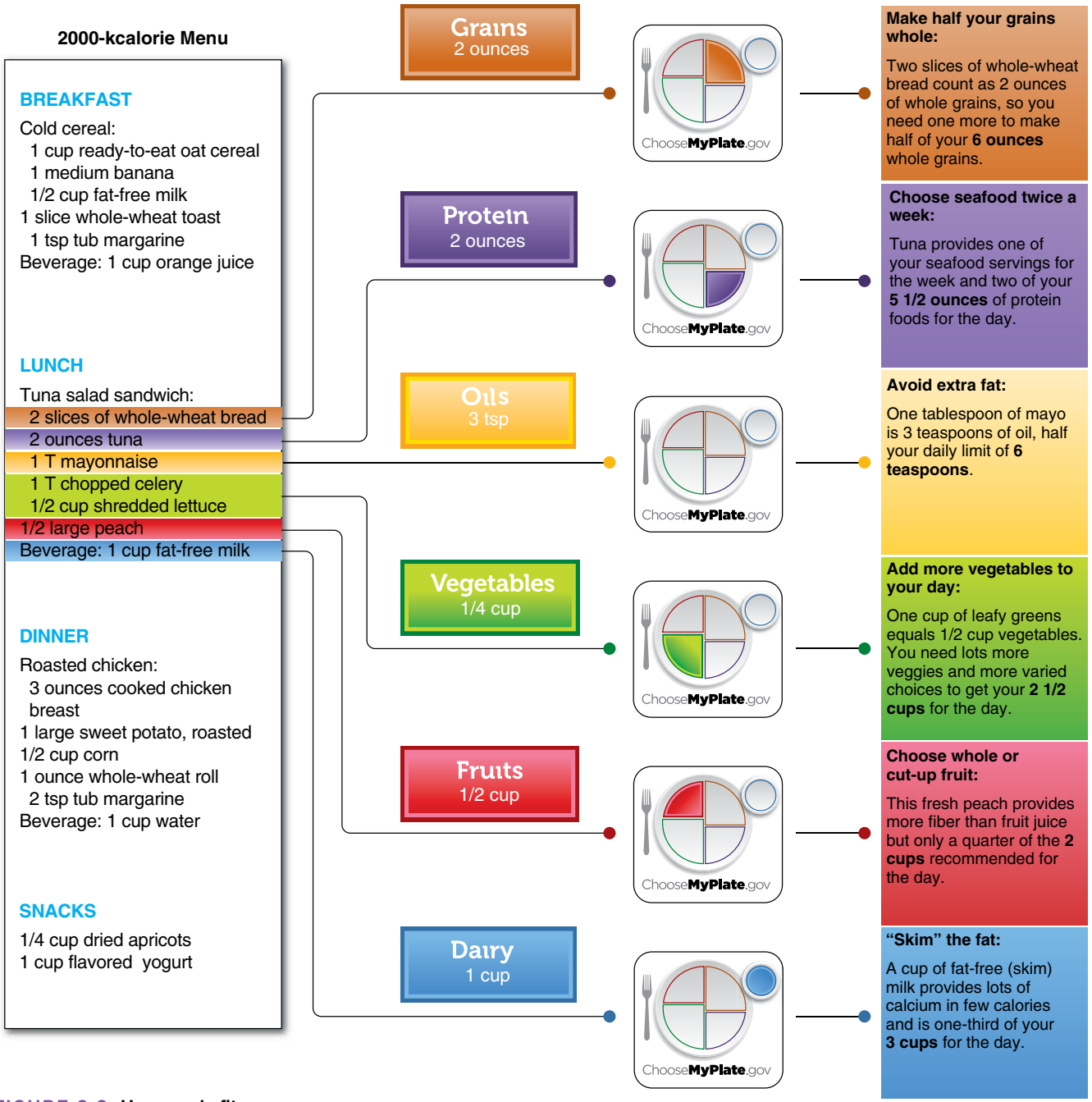


FIGURE 2.9 How meals fit
The lunch, which is highlighted in the 2000-kcal menu shown here, includes about a third of the amounts of grains, protein foods, and dairy recommended for the day, a quarter of the fruit, and half the oils but only a small proportion of the vegetables recommended. The lettuce and celery fit into the "other vegetables" category, so many vegetable choices throughout the rest of the day and week should come from dark-green, red and orange, and starchy vegetables as well as beans and peas.

MyPlate recommends at least 150 minutes of activity each week to help balance food and physical activity and includes limits for dietary sodium, saturated fat, and added sugars. Saturated and other solid fats and added sugars contribute **empty calories**. Your empty calorie allowance is the number of calories you can consume after you have satisfied all your nutrient needs from nutrient-dense food choices. These "extra" calories are needed to maintain your weight and can come from additional nutrient-dense choices or from foods that are high in

empty calories Calories from solid fats and/or added sugars, which add calories to the food but few nutrients.

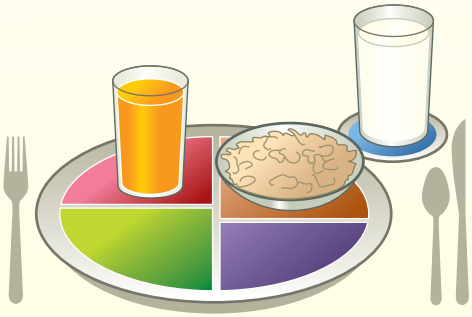
CRITICAL THINKING

Fitting Foods, Meals, and Diets onto MyPlate

Joe Gough/Shutterstock

For the first time in his life, Lucas is shopping and cooking for himself. He wants to prepare healthy meals so he uses MyPlate as a guide for his food choices. He is a 22-year-old male who exercises less than 30 minutes a day.

For breakfast Lucas has cereal, milk, orange juice, and coffee with cream and sugar. When he puts the foods from this meal on MyPlate he notices that the sections for vegetables and protein foods are empty.



Where do the cream and sugar he puts in his coffee fit onto MyPlate?

For dinner Lucas has lasagna. To see how it fits onto MyPlate, he breaks it down into individual ingredients.

Complete the table below to see how his lasagna fits onto MyPlate. (*Hint:* Use Food-A-Pedia in SuperTracker at ChooseMyPlate.gov)

INGREDIENTS IN LASAGNA	FOOD GROUP	AMOUNT ON MYPLATE
Noodles (1.5 oz dry)		
Tomato sauce (¾ cup)		
Ground beef (2 oz)		
Mozzarella cheese (3 T)		
Ricotta cheese (¼ cup)		
Olive oil (1 tsp)		

If he used butter instead of olive oil, where would it fit on MyPlate?

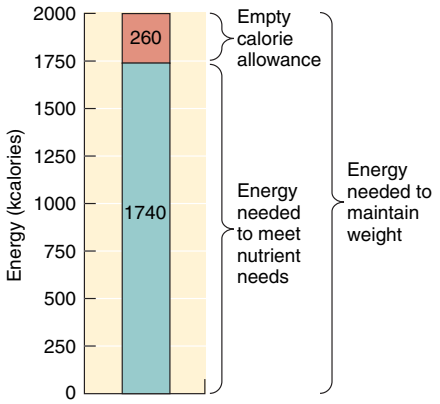
iProfile Use iProfile to find nutrient-dense substitutions for foods that are high in empty calories

CRITICAL THINKING QUESTIONS

- **Does Lucas need to include foods from each group at every meal? Why or why not?**
- **Plan a lunch for Lucas that includes a food from each food group of MyPlate.**

added sugar or solid fats (Figure 2.10A). Some empty calories come from foods, such as butter, table sugar, soft drinks, and candy, that don't belong in any food group because all their calories are empty. Some empty calories come from foods that belong to a food group but contain added

FIGURE 2.10 Limit foods high in empty calories



A. If you are at a healthy weight and you choose nutrient-dense foods, you can satisfy all your nutrient needs with fewer calories than you need to maintain your weight. The extra calories needed to maintain your weight are your empty calorie allowance.

Food group	Foods with few or no empty calories	Foods with about half their energy from empty calories
Grains	Whole-wheat bread	Blueberry muffin
	Brown rice	Croissant
	Plain bagel	Doughnuts
	Oatmeal	Chocolate chip cookies
Vegetables	Steamed broccoli	Broccoli and cream sauce
	Sweet potatoes	Candied sweet potatoes
	Green beans	Green bean casserole
Fruits	Raw apples	Apple pie
	Strawberries	Frozen sweetened strawberries
	Fresh peaches	Canned peaches in heavy syrup
Dairy	Fat-free or low-fat milk	Whole milk
	Nonfat plain yogurt	Fruit-flavored low-fat yogurt
	Nonfat mozzarella	Cheddar cheese
Protein	Extra lean ground beef	Sausage
	Roasted chicken breast without skin	Fried chicken with skin
	Kidney beans	Bologna

© Deborah Reny/iStockphoto

B. Doughnuts are in the grains group, but about half of their calories are empty calories from solid fat and sugar. The foods included in the right column of the table all belong to food groups but have so much solid fat or added sugar that about half of their energy is from empty calories. The foods in the left column have few or no empty calories.

sugars and solid fats (Figure 2.10B). Oils are healthy fats, so they are not considered empty calories. It is important to limit empty calories because consuming too many means you can't meet your nutrient needs without exceeding your calorie needs.

One way to see how your daily intake matches the MyPlate recommendations is to use the interactive tools (SuperTracker) on the MyPlate website to help track your progress toward choosing a healthy diet.

2.5 Food and Supplement Labels

LEARNING OBJECTIVES

- Assess the amount of saturated fat in a food by using the Nutrition Facts label.
- Review a food label and identify the ingredients that are present in the greatest and least amounts.
- Use a dietary supplement label to determine the types and amounts of ingredients the product provides.
- Distinguish nutrient content claims, health claims, and structure/function claims.
- Discuss the nutrition information available for food sold in restaurants.

The Dietary Guidelines and MyPlate recommend appropriate amounts of nutritious foods, but sometimes it is difficult to tell how nutritious a particular food is. How do you know whether your frozen entree is a good source of iron, how much fiber your breakfast cereal provides, or how much calcium is in your daily vitamin/mineral supplement? You can find this information on food and supplement labels.

Food Labels

Standardized food labels are designed to help consumers make healthy food choices by providing information about the nutrient composition of foods and how they fit into the overall diet. The FDA regulates the labeling of all foods except meat and poultry products, which are regulated by the USDA.

All labels are required to contain basic product information such as the name of the product; the net contents or weight; the date by which the product should be sold; and the name and place of business of the manufacturer, packager, or distributor. In addition, most food labels contain a Nutrition Facts panel and a list of the food's ingredients.

Understanding the Nutrition Facts Since 1990, the Nutrition Facts panel has provided nutrition information about packaged foods. It provides information about serving size; total Calories (on food labels "Calorie" with a capital "C" is used to represent kcal); Calories from fat; the amounts of total fat, saturated fat, *trans* fat, cholesterol, sodium, total carbohydrate, dietary fiber, sugars, and protein per serving; and how the food fits into the overall diet (**Figure 2.11A**). The only major change that has been made to this standard format since it was introduced is the addition of *trans* fat to the label in 2006. In 2013, the Food Labeling Modernization Act was introduced in Congress, proposing changes in the Nutrition Facts label based on current understanding of nutrition science with the goal of providing consumers with more accessible information.[15] If passed, manufacturers will have 2 years to make required changes to their food labels (**Figure 2.11B**).

What Is the Serving Size? The serving sizes listed on the Nutrition Facts panel are standardized to allow comparisons to be made easily between products. They are given in common household and metric measures and are followed by the number of servings per container. For example, comparing the Calories per serving of different types of cookies is simplified because all packages list energy values for a 1-ounce serving and tell you the number of cookies per serving. The standard serving sizes on food labels were developed based on what people actually ate. Since people today tend to eat larger portions than when the serving sizes were originally developed, proposed changes to the food label will change serving size requirements to reflect the amounts people eat and drink today.[15]

Daily Value A nutrient reference value used on food labels to help consumers see how foods fit into their overall diets.

Reference Daily Intakes (RDIs) Reference values established for vitamins and minerals that are based on the highest amount of each nutrient recommended for any adult age group by the 1968 RDAs.

Daily Reference Values (DRVs) Reference values established for protein and seven nutrients for which no original RDAs were established. The values are based on dietary recommendations for reducing the risk of chronic disease.

How to Use Daily Values Food labels list the amounts of most nutrients as a percentage of a standard called the **Daily Value**. Daily Values help consumers determine how a food fits into their overall diet. The % Daily Value is the amount of a nutrient in a food as a percentage of the recommendation for a 2000-kcal diet. For example, if a food provides 10% of the Daily Value for dietary fiber, then the food provides 10% of the recommended daily intake for dietary fiber in a 2000-kcal diet. As a general rule, a Daily Value of 5% or less indicates that the food is low in that nutrient and a Daily Value of 20% or more indicates that it is high. For most nutrients, the Daily Value is a target for intake, but for some, such as total fat, saturated fat, and cholesterol, it is a maximum recommended amount. For these you would want to select foods with a low % Daily Value. So, for example, if a food contains 5% of the Daily Value for saturated fat, then it contains only 5% of the maximum amount recommended for a 2000-kcal diet. Proposed food label changes would update the Daily Values for nutrients for which we now have a greater understanding such as sodium, dietary fiber, and vitamin D.

Because the Daily Values are a single set of standards for everyone, they may overestimate the amount of a nutrient needed for some groups, but they do not underestimate the requirement for any group (except pregnant and lactating women). Daily Values are based on two sets of standards, the **Reference Daily Intakes (RDIs)** and the **Daily Reference Values (DRVs)** (see Appendix B). To avoid confusion, only the term "Daily Value" appears on food labels.

FIGURE 2.11 Interpreting the current and proposed Nutrition Facts panel

A. The current Nutrition Facts panel can help you evaluate the nutritional contribution a food makes to your diet.

Standard serving sizes are required to allow consumers to compare products. For example, the number of calories in one serving of this product can be compared to the number of calories in a similar product because the values for both are for a standard 2/3rd-cup serving.

Food labels must list the "% Daily Value" for total fat, saturated fat, cholesterol, sodium, total carbohydrate, and dietary fiber, as well as for vitamins A and C, calcium, and iron. A % Daily Value of 5% or less is considered low, and a value of 20% or more is considered high.

The label provides information about the amounts of nutrients whose intake should be limited—total fat, saturated fat, *trans* fat, cholesterol, and sodium.

The label provides information about the amounts of nutrients that tend to be low in the American diet—fiber, vitamins A and C, calcium, and iron.

The footnote gives the Daily Values for 2000- and 2500-kcal diets to illustrate that for some nutrients the Daily Value increases with increasing caloric intake.

Nutrition Facts

Serving Size 2/3 cup (55g)
Servings Per Container About 8

Amount Per Serving

Calories 230 **Calories from Fat** 40

	% Daily Value*
Total Fat 8g	12%
Saturated Fat 1g	5%
Trans Fat 0g	
Cholesterol 0mg	0%
Sodium 160mg	7%
Total Carbohydrate 37g	12%
Dietary Fiber 4g	16%
Sugars 1g	
Protein 3g	
Vitamin A	10%
Vitamin C	8%
Calcium	20%
Iron	45%

* Percent Daily Values are based on a 2,000 calorie diet. Your daily value may be higher or lower depending on your calorie needs.

Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

ANALYZE THE DATA

How much sodium would you consume if you ate 2 cups of this product? What percentage of the Daily Value would that represent?

B. This revised Nutrition Facts panel illustrates the changes proposed to help consumers make informed food choices and follow guidelines for a healthy diet.

Nutrition Facts

8 servings per Container

Serving size 2/3 cup (55g)

Amount Per 2/3 cup

Calories 230

12%	**Total Fat** 8g
5%	Saturated Fat 1g
	Trans Fat 0g
0%	**Cholesterol** 0mg
7%	**Sodium** 160mg
12%	**Total Carbs** 37g
16%	Dietary Fiber 4g
	Sugars 1g
	Added Sugars 0mg
	Protein 3g
10%	**Vitamin D** 2mcg
20%	**Calcium** 200mg
45%	**Iron** 8 mg
5%	**Potassium** 235mg

* Footnote on Daily Values (DV) and calories reference to be inserted here.

Standard serving sizes will be updated based on what people actually eat, not on what they should eat. The information on servings per container will also be in a larger, bolder font.

The Calories per serving will be more prominent to highlight this information, which is important to address current public health concerns such as obesity, diabetes, and heart disease.

The % Daily Values will be listed in front of the nutrients and the Daily Values used to calculate the % Daily Value will be updated.

Information about amounts of nutrients that should be limited will include added sugars.

The information on nutrients that tend to be low in the diet will include potassium and vitamin D along with iron and calcium. Vitamins A and C will not be required. Actual amounts of these nutrients as well as % Daily Values will be included.

A new footnote will more clearly explain the meaning of % Daily Values

OFF THE LABEL

Using Food Labels to Choose Wisely

© iStockphoto

Food labels can't help you include more vegetables and fruits in your diet each day or ensure that you select a varied diet, but they do provide you with a good source of nutrition information. For example, for breakfast you might choose granola with whole milk or oatmeal made with nonfat milk. Which is the better choice if you want your diet to be low in added sugar and saturated fat, and high in nutrient density? You can see on the label that a cup of whole milk provides 150 kcal and 5 g of saturated fat. These 5 g of saturated fat represent 25% of the Daily Value—that is, 25% of the maximum amount of saturated fat recommended per day for a 2000-kcal diet. A cup of nonfat milk, in contrast, contains no saturated fat and only 90 kcal. Both contain only the sugar that is naturally present in milk, are good sources of calcium and vitamins A and D, and are in the dairy group. But because nonfat milk contributes fewer calories and no saturated fat, choosing it makes it easier to meet the Dietary Guidelines recommendation to limit empty calories and consume less than 10% of calories from saturated fat.

Granola and oatmeal each provide a serving from the grains group—both contain whole grains—but the amounts of fat and added sugars differ. A ½ cup serving of granola provides 230 kcal and 9 g of fat, 3.5 of which is saturated. A ½ cup of cooked oatmeal has only 150 kcal and 3 g of fat, 0.5 of which is saturated. The ingredient list reveals that oatmeal contains only rolled oats. No sugars are added. In contrast, the granola contains rolled oats plus brown sugar and honey in addition to other ingredients. The oatmeal is lower in calories from both saturated fat and added sugar, so it is higher in nutrient density.

Knowing how to interpret the information on food labels can help you choose a diet that meets the recommendations of the Dietary Guidelines and MyPlate. However, this doesn't mean you can never have a doughnut for breakfast because the label identifies it as high in fat, sugars, and calories. Even a sugary, high-fat food choice can be part of a healthy diet as long as it is balanced with healthy low-fat, low-sugar choices throughout the day. Remember, it is your total dietary pattern—not each choice—that counts.

THINK CRITICALLY: Suggest some changes to food labels in addition to those proposed that you think would help consumers identify nutrient-dense foods.

Nonfat Milk

Nutrition Facts
Serving Size 1 cup (236 ml)
Servings per Container 16

Amount Per Serving	
Calories 90	Calories from Fat 0
	% Daily Value*
Total Fat 0g	**0%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol less than 5mg	**1%**
Sodium 125mg	**5%**
Total Carbohydrate 13g	**4%**
Dietary Fiber 0g	**0%**
Sugars 12g	
Protein 9g	

INGREDIENTS: GRADE A FAT FREE SKIM MILK. VITAMIN A PALMITATE AND VITAMIN D3

Whole Milk

Nutrition Facts
Serving Size 1 cup (236 ml)
Servings per Container 16

Amount Per Serving	
Calories 150	Calories from Fat 70
	% Daily Value*
Total Fat 8g	**12%**
Saturated Fat 5g	**25%**
Trans Fat 0g	
Cholesterol 35mg	**11%**
Sodium 125mg	**5%**
Total Carbohydrate 12g	**4%**
Dietary Fiber 0g	**0%**
Sugars 12g	
Protein 8g	

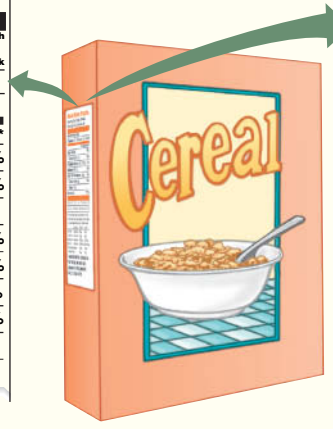
INGREDIENTS: MILK

Old-Fashioned Oats

Nutrition Facts
Serving Size 1/2 cup (40 g) dry
Servings Per Container about 13

Amount Per Serving	Dry	Cereal with 1/2 cup Skim Milk
Calories	150	190
Calories from Fat	25	30
	% Daily Value*	
Total Fat 3g	**5%**	**5%**
Saturated Fat 0.5g	**3%**	**3%**
Trans Fat 0g		
Cholesterol 0mg	**0%**	**0%**
Sodium 0mg	**0%**	**3%**
Total Carbohydrate 27g	**9%**	**11%**
Dietary Fiber 4g	**16%**	**16%**
Sugars 0g		
Protein 5g		

INGREDIENTS: 100% ROLLED OATS



Natural Granola

Nutrition Facts
Serving Size 1/2 cup (51g)
Servings Per Container about 16

Amount Per Serving	
Calories 230	Calories from Fat 80
	% Daily Value*
Total Fat 9g	**13%**
Saturated Fat 3.5g	**18%**
Trans Fat 1g	
Polyunsaturated Fat 1g	
Monounsaturated Fat 4g	
Cholesterol 0mg	**0%**
Sodium 20mg	**1%**
Potassium 250mg	**7%**
Total Carbohydrate 34gt	**11%**
Other Carbohydrate 15g	
Dietary Fiber 3g	**13%**
Sugars 16g	
Protein 5g	

INGREDIENTS: Whole grain rolled oats, whole grain rolled wheat, brown sugar, raisins, dried coconut, almonds, partially hydrogenated cottonseed and soybean oils, nonfat dry milk, glycerin, honey.

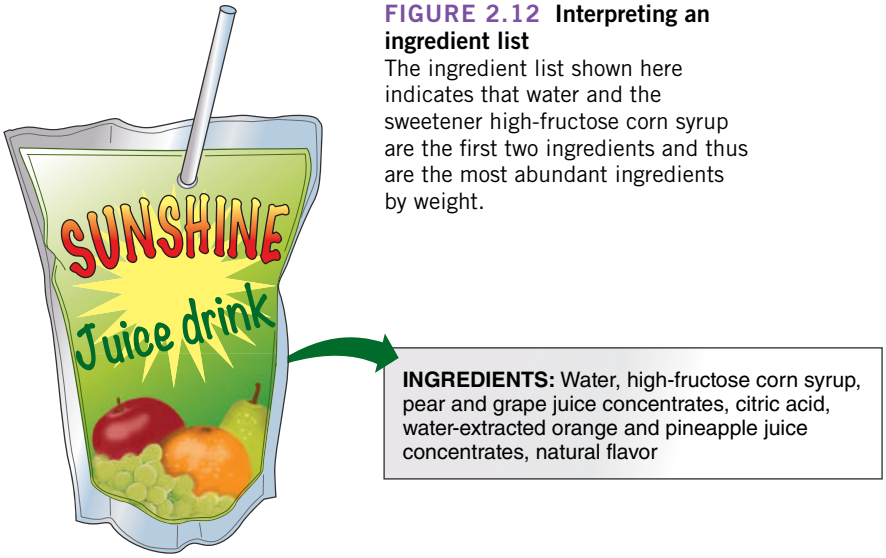


FIGURE 2.12 Interpreting an ingredient list
The ingredient list shown here indicates that water and the sweetener high-fructose corn syrup are the first two ingredients and thus are the most abundant ingredients by weight.

What the Ingredient List Tells You The ingredients section of the label lists the contents of the product in order of their prominence by weight (Figure 2.12). An ingredient list is required on all products containing more than one ingredient. Food additives, including food colors and flavorings, must be listed among the ingredients (see **Off the Label: Using Food Labels to Choose Wisely**).

Dietary Supplement Labels

Over half of all American adults regularly take some kind of supplement, typically to promote overall health and wellness or to ensure adequate nutrient intake.[16] These products, which can include vitamins; minerals; herbs, botanicals, or other plant-derived substances; amino acids; enzymes; concentrates; and extracts, must carry a standard label that meets the specifications of the Dietary Supplement Health and Education Act of 1994.[17] Each product must include a statement of identity on the label and carry a Supplement Facts panel similar to the Nutrition Facts panel found on most processed foods (Figure 2.13). This panel lists the recommended serving size and the name and quantity of each ingredient per serving. The source of the ingredient may be given with its name in the Supplement Facts panel or in the ingredient list below the panel. The nutrients for which Daily Values have been established are listed first, followed by other dietary ingredients for which Daily Values have not been established.[17] Along with changes in the Nutrition Facts label, the FDA is proposing changes to the current Supplement Facts label that will update the Daily Values and units of measure.

Supplements are classified as foods and not drugs, so they are not bound by the strict laws that regulate drug manufacturing. To help ensure that these products contain the right ingredients and the right amount per dose, the FDA established dietary supplement "current Good Manufacturing Practice" regulations. These require manufacturers to test their products to ensure identity, purity, strength, and composition.[18] The U.S. Pharmacopeia (USP) Convention, which sets the standards for drug manufacturing, has also developed the USP Dietary Supplement Verification Program (DSVP).[19] This voluntary program evaluates and confirms the contents of dietary supplements, the manufacturing processes, and compliance with standards of purity. Products that have been reviewed and meet USP criteria can use the DSVP verification mark on the label or the statement "made to US Pharmacopeia (USP) quality, purity, and potency standards" (see Figure 2.13). Consumers can be assured that products that have been USP verified contain the ingredients in the amounts as listed on the label, will disintegrate or dissolve effectively to release nutrients for absorption, meet requirements for limits on contaminants, and comply with good manufacturing practices.

Products that carry the DSVP verification mark must meet certain manufacturing standards, but they are not necessarily safe or effective. Dietary supplements do not need to be approved by the FDA for safety and effectiveness before they are marketed. According to the Dietary Supplement Health and Education Act, the manufacturer is responsible for ensuring that a supplement is safe before it is sold. If a problem arises after the supplement is on the market, it is the responsibility of the FDA to prove that the supplement represents a risk and that it should be removed from the market (see Focus on Dietary Supplements).

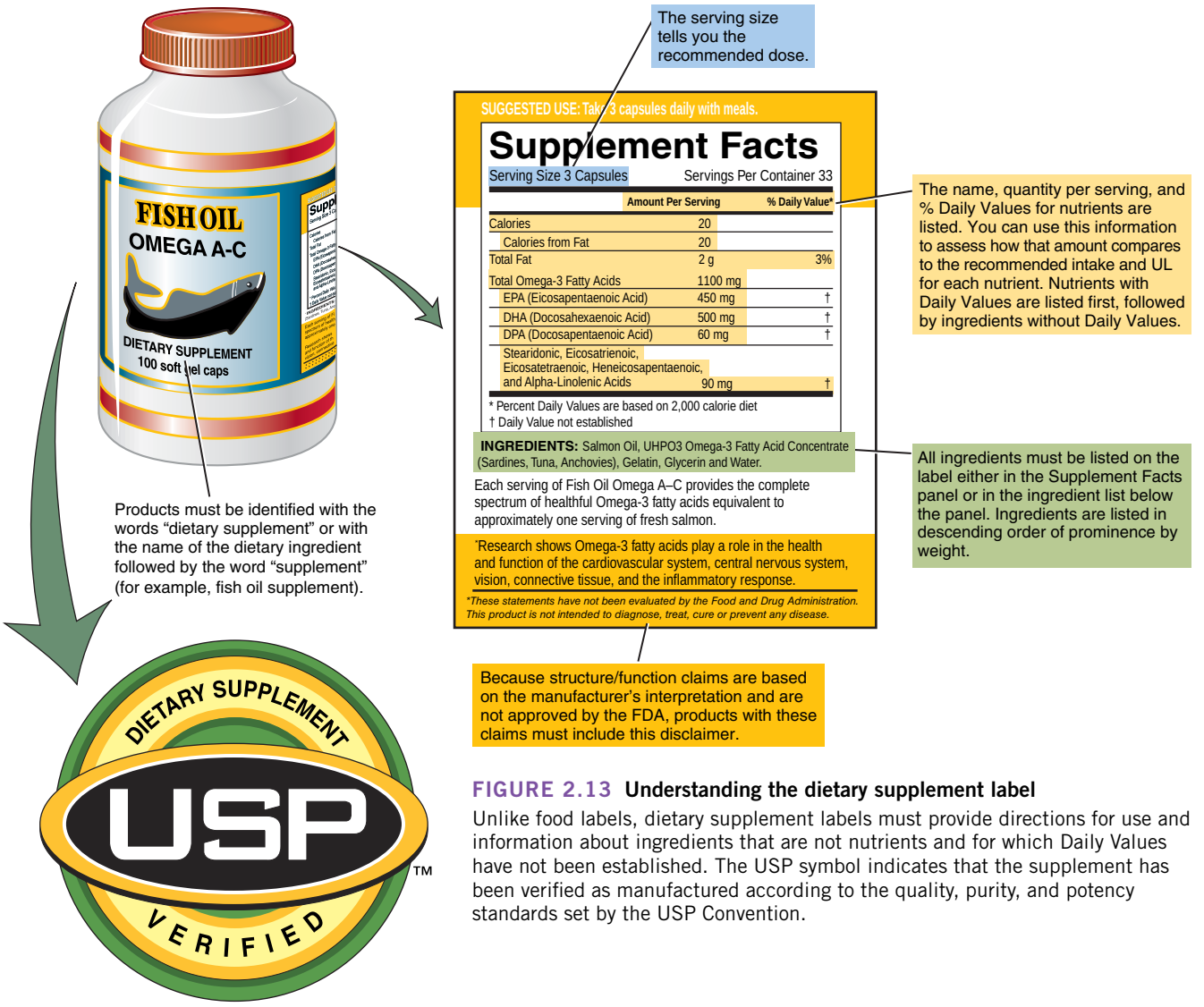


FIGURE 2.13 Understanding the dietary supplement label

Unlike food labels, dietary supplement labels must provide directions for use and information about ingredients that are not nutrients and for which Daily Values have not been established. The USP symbol indicates that the supplement has been verified as manufactured according to the quality, purity, and potency standards set by the USP Convention.

Understanding Label Claims

Three different types of claims can be used on food and dietary supplement labels: nutrient content claims, health claims, and structure/function claims.[20] The responsibility for ensuring the validity of these claims rests with the manufacturer, the FDA, or, in the case of advertising, with the Federal Trade Commission.

Nutrient Content Claims Food and supplement labels often highlight the level of a nutrient or dietary substance in a product that might be of interest to the consumer, such as "low Calorie" or "high fiber." Definitions for nutrient content descriptors such as "free," "high," and "reduced" have been established by the FDA (Table 2.5). In selecting a product labeled with a descriptor such as "fat free," consumers can be assured that the food meets the defined criteria, in this case that the product contains less than 0.5 g of fat per serving. Likewise, when selecting a supplement, the claim "excellent source of vitamin C" means that a serving of the product must contain at least 20% of the Daily Value for vitamin C. Terms like "high potency" or "antioxidant" used on supplement labels are also considered nutrient content claims. The specific definition of each of these descriptors is given in Table 2.5, and their use in relation to specific nutrients is discussed in *Off the Label* features throughout this textbook.

Health Claims Food and supplement labels are also permitted to include a number of health claims if they are relevant to the product. Health claims refer to a relationship between a food,

TABLE 2.5 Descriptors Commonly Used on Food Labels

Free	Product contains no amount of, or a trivial amount of, fat, saturated fat, cholesterol, sodium, sugars, or calories. For example, "sugar free" and "fat free" both mean less than 0.5 g per serving. Synonyms for "free" include "without," "no," and "zero."
Low	Used for foods that can be eaten frequently without exceeding the Daily Value for fat, saturated fat, cholesterol, sodium, or calories. Specific definitions have been established for each of these nutrients. For example, "low fat" means that the food contains 3 g or less per serving, and "low cholesterol" means that the food contains 20 mg or less of cholesterol per serving. Synonyms for "low" include "little," "few," and "low source of."
Lean and extra lean	Used to describe the fat content of meat, poultry, seafood, and game meats. "Lean" means that the food contains less than 10 g of fat, less than 4.5 g of saturated fat, and less than 95 mg of cholesterol per serving and per 100 g. "Extra lean" means that the food contains less than 5 g of fat, less than 2 g of saturated fat, and less than 95 mg of cholesterol per serving and per 100 g.
High	Used for foods that contain 20% or more of the Daily Value for a particular nutrient. Synonyms for "high" include "rich in" and "excellent source of."
Good source	Food contains 10 to 19% of the Daily Value for a particular nutrient per serving.
Reduced	Nutritionally altered product contains 25% less of a nutrient or of energy than the regular or reference product.
Less	Food, whether altered or not, contains 25% less of a nutrient or of energy than the reference food. For example, pretzels may claim to have "less fat" than potato chips. "Fewer" may be used as a synonym for "less."
Light	Used in different ways. It can be used on a nutritionally altered product that contains one-third fewer calories or half the fat of a reference food. It can be used when the sodium content of a low-calorie, low-fat food has been reduced by 50%. The term "light" can also be used to describe properties such as texture and color as long as the label explains the intent—for example, "light and fluffy."
More	Serving of food, whether altered or not, contains a nutrient that is at least 10% of the Daily Value more than the reference food. This definition also applies to foods using the terms "fortified," "enriched," or "added."
Healthy	Used to describe foods that are low in fat and saturated fat and contain no more than 360 mg of sodium and no more than 60 mg of cholesterol per serving and provide at least 10% of the Daily Value for vitamins A or C, or iron, calcium, protein, or fiber.
Fresh	Used on foods that are raw and have never been frozen or heated and contain no preservatives.
High potency	Used on foods or supplements to describe individual vitamins or minerals that are present at 100% or more of the Daily Value or on multi-ingredient foods or supplement products that contain 100% or more of the Daily Value for at least two-thirds of the vitamins and minerals present in significant amounts (e.g., "High-potency multivitamin, multimineral dietary supplement tablets").
Antioxidant	Used to describe foods or supplements that are "a good source of" or "high in" a nutrient for which there is an established Daily Value and for which there is scientific evidence of its function as an antioxidant.

Source: U.S. Food and Drug Administration.

food component, or dietary supplement ingredient and the risk of a disease or health-related condition. They can help consumers choose products that will meet their dietary needs or health goals. For example, low-fat milk, a good source of calcium, might include on the package label a statement indicating that a diet high in calcium will reduce the risk of developing osteoporosis.

The FDA reviews all health claims, but there are three different paths that can lead to the authorization of a health claim. The first is the most stringent. These health claims are authorized after an extensive review of the scientific evidence and are said to meet the *significant scientific agreement* standard (**Figure 2.14**). A second way to authorize a health claim on foods (but not supplements) is based on a statement of support, called an *authoritative statement*, from an appropriate scientific body of the U.S. government or the National Academy of Sciences. Finally, some health claims are approved when there is emerging but not well-established evidence for a relationship between a food, food component, or dietary supplement and reduced risk of a disease or health-related condition. These are called *qualified health claims* and must be accompanied by a statement explaining this so they do not mislead the consumer (see Figure 2.14 and online Appendix H).

Structure/Function Claims Structure/function claims describe the role of a nutrient or dietary ingredient in maintaining normal structure or function in humans. For example, a structure/function claim about calcium may state that "calcium builds strong bones." These claims may also describe the general well-being that arises from consumption of a nutrient or dietary supplement, such as "fiber maintains bowel regularity." Some structure/function claims also describe a benefit in relation to a nutrient-deficiency disease, such as "vitamin C prevents scurvy." These

FIGURE 2.14 Health claims on food labels
Oatmeal contains enough soluble fiber to be permitted to include on the label a health claim about the relationship between soluble fiber and the risk of heart disease. Other authorized and qualified health claims that can appear on food and supplement labels are listed in the table.

© JoeLena/iStock/Getty Images

4 grams of soluble fiber from oatmeal daily in a diet low in saturated fat and cholesterol may reduce the risk of heart disease

Authorized health claims: Based on significant scientific agreement

- Calcium intake and calcium and vitamin D intake and the risk of osteoporosis
- Sodium intake and the risk of high blood pressure
- Saturated fat and cholesterol intake and the risk of coronary heart disease
- Grain products, fruits, and vegetables that contain fiber and the risk of some types of cancer
- Grain products, fruits, and vegetables that contain fiber, particularly soluble fiber, and the risk of coronary heart disease
- Fruit and vegetable intake and the risk of certain types of cancer
- Soluble fiber from certain foods and the risk of coronary heart disease
- Soy protein and the risk of coronary heart disease
- Dietary fat and the risk of some cancers
- Folic acid and a woman's risk of having a child with a brain or spinal cord defect
- Sugar alcohols and other noncariogenic carbohydrate sweeteners and the risk of dental caries
- Plant sterol/stanol esters and risk of coronary heart disease

Authorized health claims: Based on an authoritative statement

- Whole-grain foods and the risk of heart disease and certain cancers
- Potassium and the risk of high blood pressure and stroke
- Fluoridated water and reduced risk of dental caries
- Saturated fat, cholesterol, and *trans* fat and reduced risk of heart disease

Qualified health claims

- Qualified claims about cancer risk: Tomatoes and/or tomato sauce and prostate, ovarian, gastric, and pancreatic cancers; calcium and colon/rectal cancer and calcium and recurrent colon/rectal polyps; green tea and cancer; selenium and cancer; antioxidant vitamins and cancer
- Qualified claims about cardiovascular disease risk: Nuts and heart disease; walnuts and heart disease; omega-3 fatty acids and coronary heart disease; B vitamins and vascular disease; monounsaturated fatty acids from olive oil and coronary heart disease; unsaturated fatty acids from canola oil and coronary heart disease; corn oil and heart disease
- Qualified claims about cognitive function: Phosphatidylserine and cognitive dysfunction and dementia
- Qualified claims about diabetes: Chromium picolinate and diabetes
- Qualified claims about hypertension: Calcium and hypertension, pregnancy-induced hypertension, and preeclampsia
- Qualified claims about neural tube birth defects: 0.8 mg folic acid and neural tube birth defects

statements must also tell how widespread the disease is in the United States. Structure/function claims are not approved by the FDA. They are based on the manufacturer's review and interpretation of the scientific literature and are not supposed to be untrue or misleading, but they can be confusing. For example, the health claim "lowers cholesterol" requires FDA approval, but the structure/function claim "helps maintain normal cholesterol levels" does not. It would not be unreasonable for consumers with high cholesterol to conclude that a product that "helps maintain normal cholesterol levels" would help lower their elevated blood cholesterol level to within the normal range. Structure/function claims must be accompanied by the disclaimer that "This statement has not been evaluated by the Food and Drug Administration. This product is not intended to diagnose, treat, cure, or prevent any disease" (see Figure 2.13).

What Must Be Labeled?

Food labels are required on all packaged foods except those produced by small businesses and those in packages too small to accommodate the information. But what about food that doesn't come in a package?

Fresh Grocery Products The Dietary Guidelines recommend Americans eat more fresh fruits, vegetables, and seafood, but raw fruits, vegetables, and seafood are currently not required to

Chris Hondros/Getty Images

THINK CRITICALLY

Do you think calorie labeling is an effective strategy for getting Americans to eat less? Why or why not?

FIGURE 2.15 Menu calorie labeling
Many chain restaurants already comply with regulations that require them to list calorie information for standard menu items on menus and menu boards. These requirements cover meals at take-out and sit-down restaurants, food sold at drive-through windows, muffins from coffee shops and bakeries, and even popcorn at the movies.

carry individual labels. The FDA has asked grocery stores to voluntarily provide nutrition information for the raw fruits, vegetables, and seafood most frequently eaten in the United States. The information can appear on large placards or in consumer pamphlets or brochures. Most fresh meat and poultry (whole cuts and ground and chopped products) are required to have a Nutrition Facts label on the package. Those that are not packaged must have the equivalent information displayed nearby.[21]

Food Sold in Restaurants and Vending Machines Americans consume about a third of their total calories from foods prepared outside the home. To help people recognize the calorie and nutrient content of foods consumed away from home, the FDA has established labeling requirements for restaurant menus and foods sold in vending machines. When the regulations take effect restaurants that are part of a chain of 20 or more locations will be required to display calorie information for standard items on menus or menu boards next to the name or price of the item (Figure 2.15).[22] Additional written nutrition information, including total fat, saturated fat, *trans* fat, cholesterol, sodium, total carbohydrates, sugars, fiber, and protein, will be available upon request. To help consumers put the calorie information in the context of their total daily diet, the following reminder will be included on menus and menu boards: "2000 calories a day is used for general nutrition advice, but calorie needs vary."

Restaurants that are not covered under these requirements can voluntarily register to participate. If they do not, they are only required to provide nutrition information when a claim is made about a menu item's nutritional content or health benefits, such as "low-fat" or "heart healthy." These terms mean the same on a menu as they do on food labels. For example, if you order a low-fat tostado, you can assume that "low fat" means it contains 3 g or less of fat per serving, as it would on a food label.

Vending machine operators who own or operate 20 or more vending machines will also be required to disclose calorie information for the products sold in these machines.[23] Many foods sold from vending machines already have labels that provide the number of calories, but this information is not always visible before you make your purchase.

2.6 Other Nutrition Guidelines

LEARNING OBJECTIVES

- Explain the purpose of the Healthy People Initiative.
- Discuss the uses of the Choice (Exchange) Lists.
- Describe the differences between MyPlate and the Healthy Eating Plate.

In addition to the guidelines discussed in the previous sections, other recommendations and tools for diet planning have been designed to promote a healthy diet and lifestyle. Some are part of larger government public health programs. Some are published by government organizations with the goal of promoting diets that treat or prevent specific disease. Others are generated by special interest groups and focus on specifics not addressed by government recommendations.

The Healthy People Initiative

The U.S. Public Health Service, along with hundreds of private and public organizations, has developed a set of public health objectives called Healthy People. This set of health promotion and disease prevention objectives is designed to increase the quality and length of healthy lives for the population as a whole and eliminate health disparities among different segments of the population. The first set, Healthy People 2000, developed in 1990, set goals to be attained by the year 2000; the latest version has been released as Healthy People 2020.

Healthy People 2020 includes objectives designed to improve the health of all people in the United States by promoting healthy behaviors, protecting health, assuring access to quality health care, and strengthening community prevention.[24] Many of the objectives of Healthy People 2020 address improving the nutritional status of the population (see online Appendix G). For instance, Healthy People is working toward reducing the number of cancer and heart disease deaths and the prevalence of obesity in adults by promoting active lifestyles and diets that follow the MyPlate recommendations. It promotes a reduction in growth retardation in children by encouraging healthy feeding practices, including breast-feeding for infants. Other nutrition-related objectives are designed to improve the delivery of nutrition information and services.

Choice (Exchange) Lists for Meal Planning

The Diabetic Exchange Lists were created by the American Dietetic Association and the American Diabetes Association as a meal-planning guide primarily for people with diabetes. Since their development, the use of the lists has been expanded to diet planning for generally healthy diets as well as weight management. The most recent version, published as *Choose Your Foods: Food Lists for Diabetes*, has replaced the term "exchange" with "choice" to emphasize that there are many choices when planning a healthy diet.

Choice (Exchange) Lists A system of grouping foods based on their energy and macronutrient content.

The **Choice (Exchange) Lists** group foods into three basic groups—carbohydrates, proteins, and fats—and include subgroups within each group (**Table 2.6**).[25] The carbohydrate group includes food lists for starches, fruits, milk, and vegetables. It also defines a list of other high-carbohydrate foods and indicates how to fit these foods into a diet plan. The meat and meat-substitute group includes a food list with four subgroups: very lean, lean, medium-fat, and high-fat meat. The fat group includes a food list with subgroups of monounsaturated, polyunsaturated, and saturated fats (see online Appendix J).

The Choice Lists are designed so that foods within each group have similar amounts of calories, carbohydrate, protein, and fat. Therefore, any one of the foods on a list can be exchanged with any other food on the same list without altering the calories or amounts of carbohydrate, protein, or fat in the diet (**Figure 2.16**). The Choice system groups foods differently than MyPlate because the lists are designed to meet energy and macronutrient criteria, whereas the MyPlate groups are designed to be good sources of certain nutrients regardless of their energy content. For example, the serving of potatoes shown in Figure 2.16 is in the starch food list because it has about the same amount of energy, carbohydrate, protein, and fat as the bread or rice, but in MyPlate a potato is in the vegetable group because it is a good source of vitamins, minerals, and fiber.

The Choice (Exchange) Lists can be used to design diets to meet individual tastes and preferences at specific energy and macronutrient levels. For instance, a diet could be calculated to provide 1600 kcal with 200 g of carbohydrate. The consumer would meet this criteria by consuming a prescribed number of servings from each of the food lists. For example, he or she would be instructed to choose six servings from the starch list, two servings from the milk list, three from the nonstarchy vegetable list, and so on.

TABLE 2.6 Energy and Macronutrient Values of the Choice (Exchange) Lists

Food group/lists	Serving size	Energy (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Carbohydrate group					
Starch	1/3 cup pasta, ½ cup potatoes; 1 slice bread	80	15	3	0–1
Fruit	1 small apple, peach, or pear; ½ banana; ½ cup canned fruit (in juice)	60	15	0	0
Milk	1 cup milk or yogurt				
Nonfat		90	12	8	0
Low-fat		110	12	8	3
Reduced fat		120	12	8	5
Whole		150	12	8	8
Other carbohydrates	Serving sizes vary	Varies	15	Varies	Varies
Vegetables	½ cup cooked vegetables, 1 cup raw	25	5	2	0
Meat/meat substitute group	1 oz meat or cheese				
Very lean		35	0	7	0–1
Lean		55	0	7	3
Medium fat		75	0	7	5
High fat		100	0	7	8
Fat group	1 tsp butter, margarine, or oil; 1 T salad dressing	45	0	0	5

Recommendations from Special Interest Groups

Many special interest groups make recommendations that are different from those presented by the government. For example, the American Heart Association makes recommendations that are designed specifically to reduce the risk of heart disease, and the American Cancer Society makes lifestyle recommendations to reduce cancer risk. The Harvard School of Public Health and the Harvard Medical School developed the Healthy Eating Plate. It uses a graphic similar to MyPlate, but makes more specific recommendations in terms of food choices from within each group (Figure 2.17).

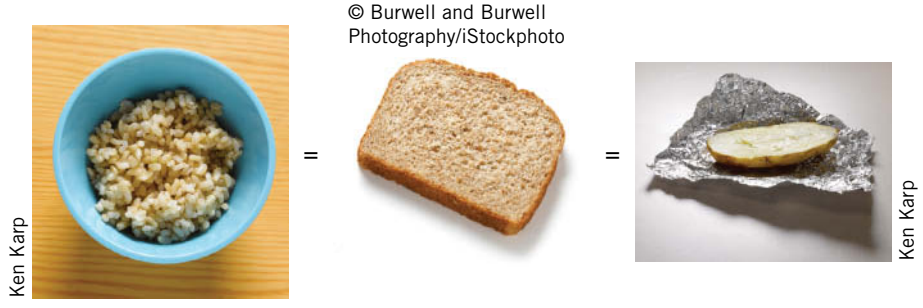


FIGURE 2.16
Exchanging foods with the same macronutrient content
Foods that are in the same food list, such as rice, bread, and potatoes, are similar in their energy and macronutrient content, so they can be exchanged for one another in a calorie-controlled diet.

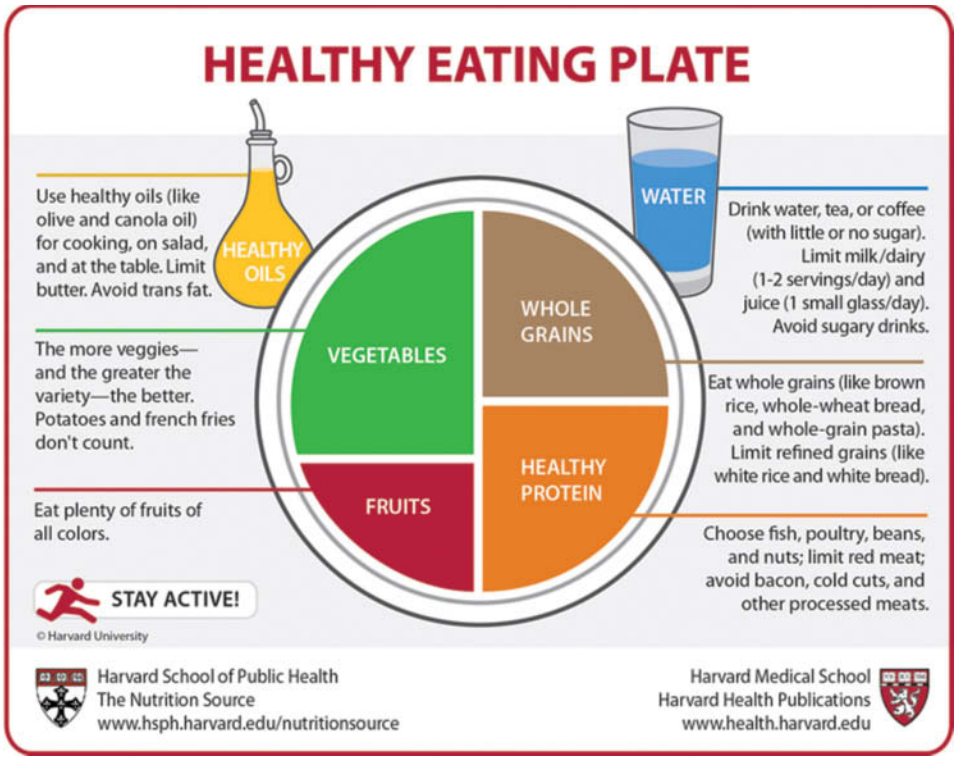


FIGURE 2.17 The Healthy Eating Plate The Healthy Eating Plate emphasizes that a healthy diet is based on whole grains, fruits, vegetables, healthy protein sources, unsweetened beverages, and oils. This food guide recommends limiting red meat, refined grains, and dairy and avoiding sugary drinks, *trans* fat, and processed meats.

Copyright © 2011 Harvard University. For more information about The Healthy Eating Plate, please see The Nutrition Source, Department of Nutrition, Harvard School of Public Health, http://www.thenutritionsource.org.

THINK CRITICALLY

How does the Health Eating Plate differ from MyPlate? Which of these tools do you think will better help Americans improve their diets? Why?

2.7 Assessing Nutritional Health

LEARNING OBJECTIVES

- Describe three types of information used in assessing nutritional status.
- Compare three methods that are used to assess food intake.
- Explain the types of tools used to assess the nutritional health of populations.

nutritional status State of health as it is influenced by the intake and utilization of nutrients.

To be healthy, people need to consume combinations of foods that provide appropriate amounts of nutrients. Scientists and public health officials have developed standards for the amounts of nutrients needed and tools for planning diets to meet these needs. But how do we know if the nutritional requirements of an individual or the population are being met? Evaluating the **nutritional status** of individuals and populations can identify nutritional needs and be used to plan diets to meet these needs.

VIDEO

nutritional assessment An evaluation used to determine the nutritional status of individuals or groups for the purpose of identifying nutritional needs and planning personal health-care or community programs to meet those needs.

How to Assess an Individual's Nutritional Status

Are you losing weight? Gaining weight? Do you have a history of heart disease in your family? Are you at risk for a nutrient deficiency because you can't get to the store, can't afford to buy healthy foods, or don't know what to eat or how to cook? An individual **nutritional assessment** helps to determine if a person has a nutrient deficiency or excess or is at risk of one, or if that individual is at risk of chronic diseases that are affected by diet. It requires a review of past and present dietary intake, a clinical assessment that evaluates body size and includes a medical history and physical exam, and laboratory measurements. Even with all these tools, diagnosing a nutritional deficiency or excess is not trivial. Estimates of dietary intake are not always accurate, and symptoms may be indistinguishable from other medical conditions.

How Dietary Intake Is Estimated Accurate information about food intake is necessary to study nutrient requirements and functions, to make nutrition recommendations for a population, and to evaluate an individual's nutritional status. Dietary intake information can be

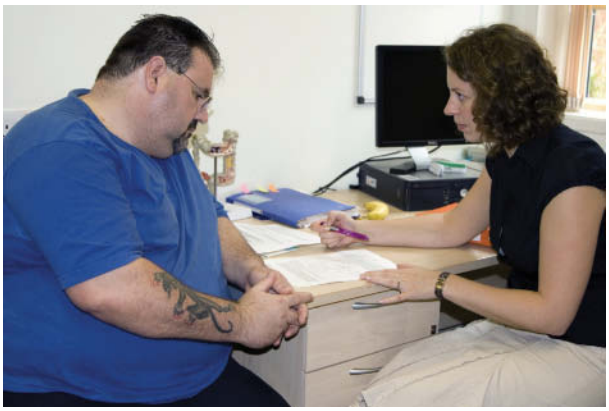
obtained by observing all the food and drink consumed by an individual for a specified period of time or by asking the person to record or recall his or her intake. Neither option is ideal. Being observed or asked to record intake can alter an individual's intake, and recording and recalling intake are imprecise measures because they depend on the memory and reliability of the consumer. In general, people tend to report consuming fewer calories than they actually eat.[26] Despite this problem, the commonly used methods described here are the best tools available for evaluating dietary intake to predict nutrient deficiencies or excesses.

24-Hour Recall The most common method of assessing dietary intake is a **24-hour recall**, in which a trained interviewer asks a person to recall exactly what he or she ate during the preceding 24-hour period. A detailed description of all food and drink, including descriptions of cooking methods and brand names of products, is recorded (Figure 2.18A). Since food intake varies from day to day, repeated 24-hour recalls by the same individual provide a more accurate estimate of typical intake.

24-hour recall A method of assessing dietary intake in which a trained interviewer helps an individual remember what he or she ate during the previous day.

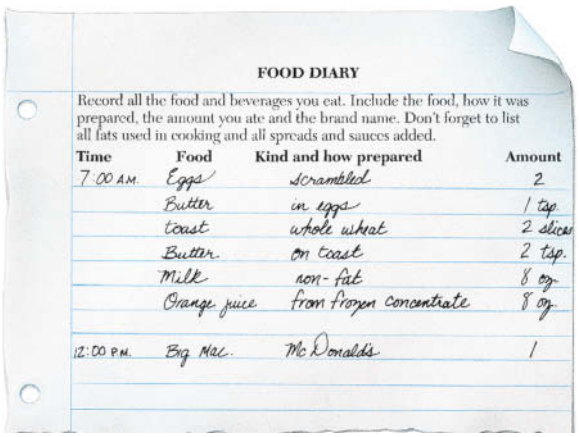
Food Diary or Food Intake Record Food intake information can also be gathered by having a consumer keep a **food diary**, or record, of all the food and drink consumed for a set period of time. Typically, this is done for two to seven days, including at least one weekend day, since most people eat differently on weekends than during the school or workweek. Foods may be weighed or measured or portion sizes just estimated (Figure 2.18B). To accurately assess intake, the record needs to be as complete as possible, including all beverages, condiments, and the brand names and preparation methods. Food records can provide detailed information, but the act of

food diary A method of assessing dietary intake that involves an individual keeping a written record of all food and drink consumed during a defined period.



Life in View/Photo Researchers, Inc.

A. 24-hour recall: The 24-hour recall method relies on a subject's memory, but because subjects don't record their intake, they are less likely than with a food record to change what they eat. This method can be used to survey large numbers of people in a short time and can be conducted by telephone.

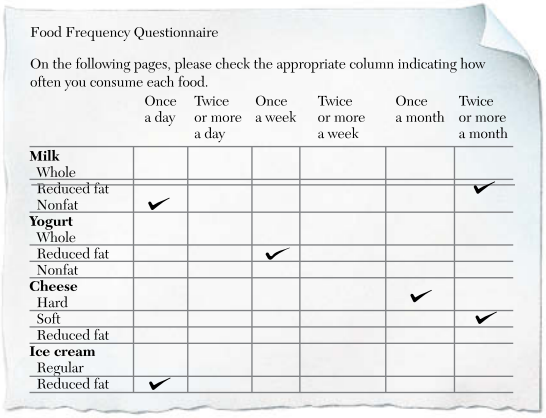


FOOD DIARY

Record all the food and beverages you eat. Include the food, how it was prepared, the amount you ate and the brand name. Don't forget to list all fats used in cooking and all spreads and sauces added.

Time	Food	Kind and how prepared	Amount
7:00 A.M.	Eggs	scrambled	2
	Butter	in eggs	1 tsp
	toast	whole wheat	2 slices
	Butter	on toast	2 tsp.
	Milk	non-fat	8 oz.
	Orange juice	from frozen concentrate	8 oz.
12:00 P.M.	Big Mac	McDonalds	1

B. Food intake record: Food records created as individuals consume their meals can be very reliable and provide detailed information, but they are time consuming for participants and can be costly and time consuming to analyze.



Food Frequency Questionnaire

On the following pages, please check the appropriate column indicating how often you consume each food.

	Once a day	Twice or more a day	Once a week	Twice or more a week	Once a month	Twice or more a month
Milk						
Whole						
Reduced fat						✓
Nonfat	✓					
Yogurt						
Whole						
Reduced fat			✓			
Nonfat						
Cheese						
Hard					✓	
Soft						✓
Reduced fat						
Ice cream						
Regular						
Reduced fat	✓					

C. Food frequency questionnaire: Food frequencies can be used to study food intake patterns, such as typical dairy product intake. They are easy for participants and relatively inexpensive for researchers to analyze.

FIGURE 2.18 Methods of assessing food intake
There are a variety of ways to determine what someone eats. Which tool is best depends on the type of information needed, how many subjects need to be surveyed, and the time and cost constraints.

recording can affect intake. Someone may decide to skip the handful of chips they would have eaten rather than record that they ate it.

food frequency questionnaire A method of assessing dietary intake that gathers information about how often certain categories of food are consumed.

Food Frequency A **food frequency questionnaire** lists a variety of foods, and the consumer is asked to estimate the frequency with which he or she consumes each item or food group: For example, "How often do you drink milk?" or "How many times a week do you eat red meat?" This method cannot be used to itemize a specific day's intake, but it can give a general picture of a person's typical pattern of food intake (Figure 2.18C).

diet history Information about dietary habits and patterns.

A Diet History Provides a Complete Picture A **diet history** collects information about dietary patterns. It may review eating habits: Do you cook your own meals? Do you skip lunch? It may also include a combination of methods to assess food intake such as a 24-hour recall along with a food frequency questionnaire. The combination of two or more methods often provides more complete information than one method alone. For instance, if an individual's 24-hour recall does not include milk but a food frequency questionnaire suggests that the individual usually drinks milk five days a week, the two can be combined to provide a more accurate picture of this individual's typical intake.

Analyzing Nutrient Intake Once information on food intake has been obtained, the nutrient content of the diet can be compared to recommended intakes. To get a general picture of dietary intake, an individual's food record can be compared to the recommendations of the Dietary Guidelines and MyPlate, or a more precise and extensive analysis of dietary intake can be done by totaling the nutrients contributed by each food item and comparing them to the DRIs.

The Healthy Eating Index (HEI) developed by the USDA is a measure of how well a diet conforms with the recommendations of the Dietary Guidelines and MyPlate.[27] It provides an index that summarizes overall diet quality by scoring 12 components of the diet. An individual who carefully follows the Dietary Guidelines would have an HEI score of 100. An HEI score over 80 implies that a person has a good diet; a score of 51 to 80, a diet that needs improvement; and a score less than 51, a poor diet. The average HEI score in the U.S. population is only 56, indicating a diet that needs improvement.[27]

A more precise analysis of nutrient intake can be made using information on the nutrient composition of foods from food labels, food composition tables, and computer databases. Food labels provide information for only some nutrients, and they are not available for all foods. Food composition tables generated by government and industry laboratories can provide more extensive information on food composition (see online *Nutrient Composition of Foods* supplement for an abbreviated list). The major source of food composition data in the United States is the USDA Nutrient Database for Standard Reference, which is available online.[28] Computer programs with food composition databases, such as **iProfile**, are available for professionals and for home use. An easy-to-use online nutrient analysis can be done by using MyPlate SuperTracker, which uses the USDA database to analyze foods and diets entered into the program.

To analyze nutrient intake correctly using a computer program, each food and the exact portion consumed must be entered into the program. If a food is not found in the computer database, an appropriate substitute can be used or the food can be broken down into its individual ingredients. For example, homemade vegetable soup could be entered as generic vegetable soup or as vegetable broth, carrots, green beans, rice, and so on. If a new product has come on the market, the information from the food label can be added to the database. The advantage of computer diet analysis is that it is fast and accurate. A program can calculate the nutrients for each day or average them over several days. It can also compare nutrient intake to recommended amounts. However, the information generated by computer diet analysis is useful only if it is entered correctly and interpreted appropriately. Also, a nutrient intake that is below the recommended amount does not always indicate a deficiency, and intake that meets recommendations does not ensure adequate nutritional status. Figure 2.19 illustrates how iProfile diet analysis software compares the nutrients in a diet with recommendations.

anthropometric measurements External measurements of the body, such as height, weight, limb circumference, and skinfold thickness.

Anthropometric Measurements Evaluating nutritional health also involves an assessment of an individual's height, weight, and body size. These **anthropometric measurements** can be compared with population standards (see online Appendix E) or used to monitor changes in an individual over time (Figure 2.20). If an individual's measurements differ significantly from the standards, it could indicate a nutritional deficiency or excess; however, this information should

Nutrient	My DRI	My Intake	Percent of My DRI (0% 50% 100%)
Vitamin A (RAE)	700 μg	525	75%
Vitamin C	75 mg	86	115%
Iron	18 mg	9.7	54%
Calcium	1000 mg	750	75%
Saturated fat	< 23.8 g	31.9	Above recommended range

FIGURE 2.19 Computerized diet analysis
In this example based on an iProfile report, which shows only a few nutrients, intake of vitamin C and saturated fat is above the recommended amounts and intake of vitamin A, calcium, and iron is below the recommended amounts.

iProfile

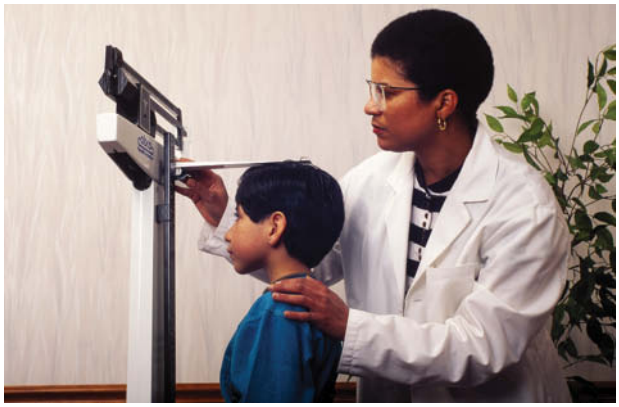
be evaluated only within the context of that person's personal and family history. For example, children who are small for their age may have a nutritional deficiency or may simply have inherited their small body size. Individuals who weigh less than the standard may be adequately nourished if they have never weighed more than their current weight and are otherwise healthy.

Medical History A medical history is an important component of a nutritional assessment because dietary needs depend on genetic background, life stage, and health status. Family history is important because the risk of developing nutrition-related diseases is affected by an individual's genes (Figure 2.21). If your mother died of a heart attack at age 50, you have a higher than average risk of developing heart disease. If you have a family history of diabetes, you have an increased risk of developing this disease. If both of your parents are overweight, it increases the chances that you, too, will have a weight problem.

LIFE CYCLE

Information about life stage is important when assessing nutritional status because nutrient needs vary at different stages. Pregnant women need more of some nutrients and energy to support the development of a healthy newborn. Energy and protein needs per unit body weight are higher in infants than at any other time of life. The needs of older adults change as their body composition changes and the ability to digest, absorb, and metabolize certain nutrients declines.

Existing health conditions can impact nutritional health. Some conditions, such as arthritis, affect the ability to acquire and prepare food. Others affect the kinds of foods that should be consumed or the way nutrients are handled by the body. For example, gastrointestinal disorders may decrease the ability to digest foods and absorb nutrients. Kidney disease alters the ability to excrete nitrogen and so affects the amount of protein that should be consumed.



Blair Seitz/Photo Researchers

FIGURE 2.20 Body measurements
Nutritional assessment includes measures of body dimensions such as height and weight, which can be monitored over time or compared with standards for a given population.

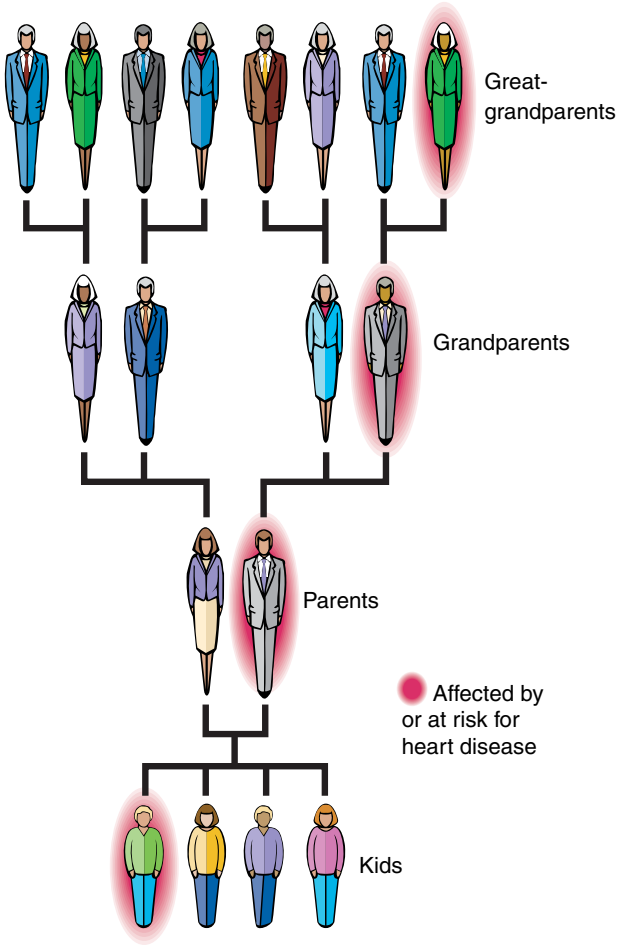


FIGURE 2.21 Family history
This family tree traces heart disease in one family. It illustrates how a person's family medical history can reveal his or her genetic predisposition for developing heart disease.

Physical Exam In conjunction with personal and family medical history, a careful physical exam can detect the symptoms of, and risk factors for, nutrition-related diseases. In a physical exam, all areas of the body including the mouth, skin, hair, eyes, and fingernails are examined for indications of poor nutritional status. Symptoms such as dry skin, cracked lips, or lethargy may indicate a nutritional deficiency, but these types of symptoms are nonspecific and may be due to factors unrelated to nutritional status. Determining whether the symptoms noted in a physical exam are due to malnutrition or another disease requires that they be evaluated not only within the context of each individual's medical history but in conjunction with the results of laboratory measurements.

Laboratory Measurements Measures of nutrients or their by-products in body cells or fluids such as blood and urine can be used to detect nutrient deficiencies and excesses (see online Appendix F). For instance, levels of zinc in the blood are used to test for zinc deficiency. For some nutrients, blood levels reflect what has been absorbed from the most recent meal rather than the total body status of the nutrient. To assess the status of these nutrients, it may be necessary to measure nutrient functions rather than just blood levels. For example, vitamin B_6 is needed for chemical reactions involved in amino acid metabolism. Measuring the rates of chemical reactions that require vitamin B_6 can be used to assess vitamin B_6 status.

Laboratory data can also be used to evaluate risk for nutrition-related chronic diseases. For instance, measuring the amount of glucose in the blood can be used to diagnose diabetes. More sophisticated medical tests can be used to obtain additional information about the risk and progression of nutrition-related diseases. For example, procedures are available to determine the extent of coronary artery blockage in an individual with heart disease or to assess bone density in someone at risk for osteoporosis.

How a Nutrient Deficiency Progresses A nutritional deficiency usually takes time to develop. For example, an individual who is not meeting the requirement for protein may not suffer any physical signs of protein deficiency for months. Deficiencies generally progress through a number of stages. Appropriate nutritional assessment tools can identify deficiencies at any of these stages and allow intervention to restore nutritional health (Figure 2.22).

The earliest stage of nutrient deficiency is intake that is inadequate to meet needs. This may occur due to a deficient diet, poor absorption, increased need, or increased losses from the body. Assessment of dietary intake can help identify low levels in the diet, and a physical exam, medical history, and laboratory tests can identify conditions that might reduce absorption or increase need or losses. The next stage of deficiency is declining nutrient stores in the body. Anthropometric measures that assess body weight and body fat can be used to monitor energy stores. Laboratory tests that measure levels of nutrients and their by-products in blood and tissues can be used to detect decreases in nutrient stores. For instance, measuring levels of the iron-containing protein ferritin in the blood can be used to detect low iron stores. The next stage of deficiency is altered biochemical or physiological functions, such as low enzyme activities or reduced amounts of regulatory or structural molecules. Finally, if a deficiency persists, function is disrupted enough that physical

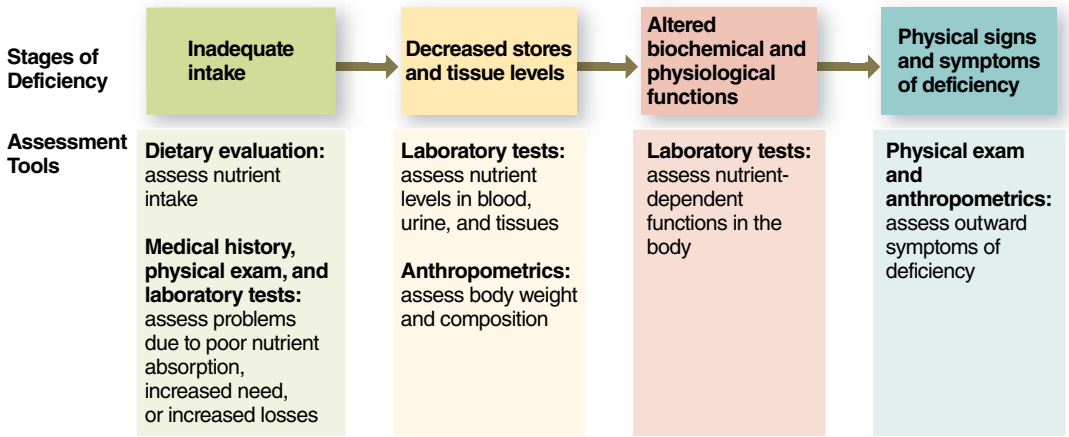


FIGURE 2.22 Assessing different stages of nutrient deficiency
Different assessment tools yield different types of information that can be used to evaluate the severity of a nutrient deficiency.

signs and symptoms, referred to as clinical symptoms, become apparent. For instance, a deficiency of iron causes fatigue, weakness, and decreased work capacity.

How the Nutritional Health of a Population Is Assessed

We know that there is enough food available in the United States to meet the needs of the population. We also know that poor nutritional choices from this food supply result in diets high in some nutrients and low in others. This kind of information is obtained by monitoring what foods are available and what is consumed. In the United States, the National Nutrition Monitoring and Related Research Program is responsible for providing an ongoing description of nutrition conditions in the population by collecting information about food availability and consumption; food composition; and the eating behaviors, health, and nutritional status of the population. These epidemiological data are gathered from population surveys. These surveys are key in establishing relationships among diet, nutritional status, and the health of the U.S. population. The information is used for the purpose of planning nutrition-related policies and programs and predicting future trends of public health importance. For example, they may help identify the need for nutrition education, food assistance programs, or the addition of a specific nutrient to the food supply.

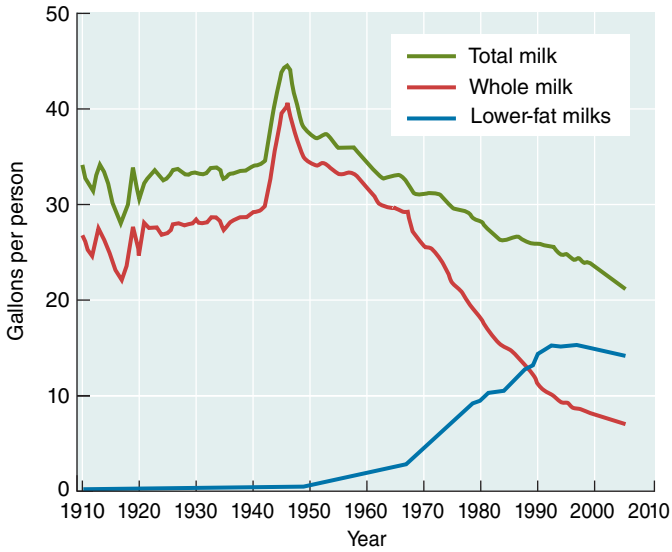


FIGURE 2.23 Trends in U.S. milk consumption
Food disappearance data in the United States from 1910 to 2005 illustrates that there was an increase in the consumption of lower-fat milks and a decrease in whole-milk consumption during the second half of the 20th century.

ANALYZE THE DATA

Can the information from this graph be used to assess the risk of low calcium intake among teens?

Monitoring the Food Supply The food available to a population is estimated using **food disappearance surveys**. The food supply includes all that is grown, manufactured, or imported for sale in the country. Food use, or "disappearance," is estimated by measuring what food is sold. These types of surveys are used to estimate what is available to the population, provide year-to-year comparisons, and identify trends in the diet; however, they tend to overestimate actual intake because they do not consider losses that occur during processing, marketing, and home use. Also, the surveys do not consider how food is distributed throughout the population. For example, Figure 2.23 illustrates the food disappearance data on milk consumption between 1910 and 2005. It shows that the consumption of whole milk, which is high in saturated fat, has declined since the 1950s and the consumption of lower-fat milks has increased. From this it can be concluded that saturated fat intake from milk has declined. But the graph also indicates that total milk consumption has been declining. This may alert the government that calcium intake from milk has decreased and that there may be a risk for low calcium intake in the population. The numbers in this graph do not give any information about how much milk each person is drinking or who is at risk for inadequate calcium intake.

food disappearance surveys A survey that estimates the food use of a population by monitoring the amount of food that leaves the marketplace.

Monitoring Nutritional Status The nutritional status of the population is monitored by examining and comparing trends in food intake and health. This is done by interviewing individuals within the population to determine what food is actually consumed and by collecting information on health and nutritional status. The Department of Health and Human Services conducts the **National Health and Nutrition Examination Survey (NHANES)**, which combines information on food consumption with medical histories, physical examinations, and laboratory measurements to monitor both nutritional and health information. Data on food, energy, and nutrient intake can be assessed by comparing population intake with reference values such as the DRIs or with other guidelines such as the recommendations of the Dietary Guidelines. For example, the NHANES data indicate that few Americans eat the recommended amounts of fruits and vegetables and that the number of people who are overweight has increased in all adult age groups during the past five decades (see **Science Applied: NHANES: A Snapshot of America's Nutritional Health**).

National Health and Nutrition Examination Survey (NHANES) A survey that collects information about the health and nutritional status of individuals in the population.

SCIENCE APPLIED

NHANES: A Snapshot of America's Nutritional Health

How do we know that over 68% of adults are overweight or obese, that obesity among children is on the rise, that almost half of women over the age of 50 have low bone density, or that American adults consume only about half the recommended amount of fruit?[29,30] Statistics such as these, along with a multitude of other health and nutrition data, are derived from the National Health and Nutrition Examination Survey, or NHANES. NHANES is the largest and longest-running survey of health *and* nutrition data for the U.S. population.

NHANES evolved from the National Health Survey Act of 1956, which established a continuing National Health Survey to obtain

National Center for Health Statistics/CDC

The NHANES mobile examination centers consist of four large trailers that travel around the country. They contain all the diagnostic equipment necessary to conduct a wide range of physical and biochemical evaluations. The survey team consists of a physician, medical and health technicians, and dietary and health interviewers.

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

information about the health status of individuals in the United States. Beginning in 1970, a nutrition emphasis was introduced because researchers began to discover links between dietary habits and disease. Since then, five NHANES have been conducted, and in 1999 it became a continuous survey that is conducted on a yearly basis.

THE SCIENCE

To provide a "snapshot" of the health and nutritional status of the U.S. population, NHANES collects data using individual interviews and physical examinations. Since it is not possible to collect data from every person residing in the United States, NHANES tries to obtain a nationally representative yet manageable sample of people. To achieve this goal, a complex sampling design is used.[31] Each survey participant theoretically represents about 50,000 other U.S. residents.

Once sampling has identified a potential survey participant, a trained interviewer conducts an initial in-home interview. Selected participants must agree to participate and sign a consent form. Then each participant visits a mobile examination center for the complete battery of medical and nutritional tests and measurements. Data are collected from physical exams, laboratory tests, and additional survey questionnaires. The nutritional assessment component of NHANES includes several types of data, as shown in the table.

Nutritional Assessment Components in NHANES

Method of assessment	What type of data is obtained?
24-hour recall and food frequency questionnaire	Food intake information
Nutrition-related interview	Information about dietary supplements, water intake, meal and snack patterns, infant feeding practices, alcohol intake, and food sufficiency
Anthropometric measurements	Height, body weight, body composition, and body circumference measures to determine body weight-fat distribution
Laboratory measurements	Blood lipid levels, blood glucose levels, and measures of protein, vitamin, and mineral status
Clinical assessments	Chronic disease risk assessment for conditions such as heart disease, diabetes, osteoporosis, and gallbladder disease

THE APPLICATION

NHANES provides health professionals and policy makers with the data needed to determine the incidence of major diseases and health conditions such as cardiovascular disease, diabetes, obesity, osteoporosis, and cancer, as well as to identify and monitor trends in medical conditions and risk factors. It helps identify emerging public health issues so that the appropriate public health policies and preventive interventions can be developed. NHANES also provides information on the prevalence and trends of risk factors and other key health behaviors, including alcohol use, tobacco use and exposure, drug use, sexual experience, immunization histories, and physical activity.

Data from NHANES have been instrumental in the development and implementation of a number of health-related guidelines and reforms and public policy initiatives. NHANES data were used to develop growth standards for children and were instrumental in reducing the manufacture and sale of lead-containing products. Nutrient intake data from the first two NHANESs indicated that certain segments of the U.S. population were not consuming adequate amounts of iron. This information led to the fortification of grain products with iron. Similarly, NHANES data that supported the connection between the B vitamin folic acid and the incidence of neural tube defects, a type of birth defect, led to the fortification of grain products with folic acid. Ongoing collection and critical analysis of NHANES data will continue to provide information on the nutritional health of the U.S. population that can be used to guide nutrient recommendations and direct nutrition policies.

THINK CRITICALLY: If NHANES data found that the incidence of type 2 diabetes has increased at about the same rate as the consumption of sugar-sweetened beverages, does this mean that sugar causes diabetes? Why or why not?

OUTCOME

Joe wanted to make sure that he was choosing a diet to optimize his fitness for the track season. MyPlate helped him decide what to put on his plate; he could see what types of foods he was consuming in excess and what types he needed more of. This helped him to better navigate the seemingly endless variety offered by the dorm cafeteria. Although he was tempted by the unlimited portions and all those great desserts, he knew that he would regret the extra pounds when it came time to run track. Instead of a big dessert every night, he grabbed some fruit to snack on later in the evening. Now that the track season has started he needs to eat more to replace the calories he burns during his intense training sessions. He finds that he can still use the MyPlate guidelines; he is eating larger portions but the same proportions of foods. **Joe started his season in excellent physical and nutritional health. His weight is right where he wants it and he feels ready to compete. His diligence is paying off, and he has been able to improve on several of his personal best times.**

SUMMARY

2.1 The Development of Nutrition Recommendations

- Our understanding of the science of nutrition has been used for over a 100 years to make nutrition recommendations. Some of these define nutrient and energy needs and others provide guidance in choosing a healthy diet.
- Nutrient deficiencies are now rare in the United States, but nutrition-related chronic diseases, such as heart disease, diabetes, osteoporosis, and obesity, are a major health problem. Current dietary guidance focuses on intakes that will avoid not only nutrient deficiencies but also avoid excesses and prevent chronic diseases in the majority of healthy persons.

2.2 Dietary Reference Intakes

- The DRIs include four sets of nutrient intake recommendations. The Estimated Average Requirements (EARs) are amounts of nutrients estimated to meet the needs of half of the people in a particular gender and life-stage group. The Recommended Dietary Allowances (RDAs), which are based on the EARs, are recommendations calculated to meet the needs of nearly all healthy individuals (97 to 98%) in a specific group. Adequate Intakes (AIs) estimate nutrient needs based on average intakes by healthy populations when there is insufficient scientific evidence to calculate an EAR and RDA. Tolerable Upper Intake Levels (ULs) provide a guide for a safe upper limit of intake.
- Energy recommendations of the DRIs include Estimated Energy Requirements (EERs), which provide a recommendation for energy intakes that will maintain body weight, and Acceptable Macronutrient Distribution Ranges (AMDRs), which recommend the proportions of energy intake that should come from carbohydrate, protein, and fat.
- The Dietary Reference Intakes can be used to evaluate and plan nutrient intakes for populations, as a guide for individual intake, and to make judgments about excessive intakes for individuals and populations.

2.3 The Dietary Guidelines for Americans

- The Dietary Guidelines for Americans are a set of diet and lifestyle recommendations designed to promote health and reduce the risk of obesity and chronic disease in the U.S. population.
- The Dietary Guidelines emphasize balancing the calories consumed in food and beverages with the calories expended through physical activity in order to achieve and maintain a healthy weight. To accomplish this, they recommend that Americans increase their activity level and choose a healthy eating pattern. Healthy eating patterns are high in fruits, vegetables, and whole grains, provide low-fat dairy products and seafood and are low in saturated fat, salt, and added sugar.

2.4 MyPlate: Putting the Dietary Guidelines into Practice

- MyPlate is the USDA's current food guide. It shows the proportions of foods from five food groups that make up a healthy diet. MyPlate stresses using variety, proportionality, and moderation in choosing a healthy diet and promotes the physical activity recommendations included in the Dietary Guidelines.
- Individual Daily Food Plans or Checklists available at www.ChooseMyPlate.gov recommend amounts of food from each food group based on individual energy needs. Recommendations are also made for the amounts of saturated fat, sodium, and added sugars that can be included in an individual's diet. Exceeding the empty calorie limit makes it difficult to meet nutrient needs without exceeding energy needs.

2.5 Food and Supplement Labels

- Nutrition Facts panels on food labels are designed to provide information about the nutrient composition of foods in a standard serving and use % Daily Values to show consumers how a food fits into the overall diet. Changes proposed to food labels would reflect the need for Americans to monitor energy and nutrients of concern in the American diet. A food label's

ingredient list states the contents of the product in order of prominence by weight.

- Labels on dietary supplements are designed to help consumers make educated decisions about these products. The safety of dietary supplements is not evaluated by the FDA before they are marketed.
- Food and supplement labels often include FDA-defined nutrient content descriptors, such as "low fat" or "high fiber," and health claims, which refer to a relationship between a nutrient, food, food component, or dietary supplement and the risk of a particular disease or health-related condition. All health claims are reviewed by the FDA and permitted only when they are supported by scientific evidence, but the level of scientific support for such claims varies. Structure/function claims describe the role of a nutrient or dietary ingredient in maintaining normal structure or function in humans. They are not approved by the FDA.
- New labeling regulations will require food establishments with 20 or more locations to include calorie-content information on menus and menu boards and make available in writing other nutrient information upon request. When requested, all restaurants must provide nutrition information when a claim is made about a menu item's nutritional content or health benefits.

2.6 Other Nutrition Guidelines

- The Healthy People Initiative establishes a set of health promotion and disease prevention objectives for the U.S. population.
- The Choice (Exchange) Lists are used to plan individual diets that provide specific amounts of energy, carbohydrate, protein, and fat.
- Alternative recommendations, such as the Healthy Eating Plate, are made by nongovernment groups.

2.7 Assessing Nutritional Health

- Individual nutritional status is assessed by evaluating dietary intake and by examining and interpreting anthropometric measures, physical exam results, and laboratory values within the context of an individual's medical history.
- The nutritional status of populations is monitored by measuring what foods are available, what foods are consumed, and how nutrient intake is related to overall health.

CHAPTER OUTLINE

3.1 Food Becomes Us
- Atoms Form Molecules
- Cells Form Tissues and Organs
- Organs Cooperate as Organ Systems

3.2 The Digestive System
- Organs of the Digestive System
- Digestive Secretions
- How Gastrointestinal Activity Is Regulated

3.3 Digestion and Absorption
- The Mouth
- The Pharynx
- The Esophagus
- The Stomach
- The Small Intestine
- The Large Intestine

3.4 The Gastrointestinal Tract and Health
- The Intestinal Microbiota
- Immune Function: How Our Gut Protects Us
- Common Digestive Complaints
- The Digestive System Throughout Life

3.5 Delivering Nutrients to Body Cells
- Why the Cardiovascular System Is Important in Nutrition
- The Roles of the Lymphatic System
- How Nutrients Enter Body Cells

3.6 Metabolism of Nutrients: An Overview
- Anabolism and Catabolism
- Producing ATP
- Synthesizing New Molecules

3.7 Elimination of Metabolic Wastes
- The Respiratory System and Skin
- The Kidneys

(©iStockphoto)

© Bojan Kontrec/iStockphoto

Digestion, Absorption, and Metabolism

3

CASE STUDY

Gillian popped two more antacids into her mouth as she hurried to the next table with a piping hot pizza balanced on her shoulder. It was becoming a regular thing—struggling through her waitress shifts with a sour taste in her mouth and pain in her chest. Sometimes the chest pain was so bad that it hurt right through to her back and she was afraid she was having a heart attack. When she talked to her friends they all said it was just heartburn and they also had it once in a while.

Gillian is a 25-year-old college student who works evenings to help pay her living expenses. She usually skips breakfast and just has coffee in the morning so she can sleep for a few more minutes before her first class. She has a piece of fruit for lunch and then eats most of her food at work, where she gets meals for free. She typically gulps down three or four slices of pizza during her breaks followed by a glass of juice. When she gets off work at 11 PM she goes right to bed in order to be up for her early class.

The sour taste and pain in her chest gets bad enough that she can't sleep; it is interfering with her class work, so she makes an appointment with her doctor. He schedules a test to check the acidity in her esophagus. The results show that she has gastroesophageal reflux disease, or GERD. GERD is a condition in which the stomach contents leak up out of the stomach into the esophagus, damaging the lining. This damage to the esophagus is painful and if the GERD is not treated it can cause ulcers, erode the enamel on her teeth, and increase her risk of esophageal cancer. Her doctor gives her a prescription for a medication that reduces acid secretion and he also tells her to make some lifestyle changes. **He hopes that these changes will reduce her symptoms and allow her esophagus to heal.**

David Woolley/Taxi/Getty Images, Inc.

3.1 Food Becomes Us

LEARNING OBJECTIVES

- Describe the organization of life from atoms to organisms.
- Name three organ systems that are involved in obtaining and using the nutrients in food.

The old adage that you are what you eat is not literally true, but biochemically it is a fact. The food we eat provides all the energy we need to stay alive and active and all the raw materials we need to build and maintain our body structures and synthesize regulatory molecules.

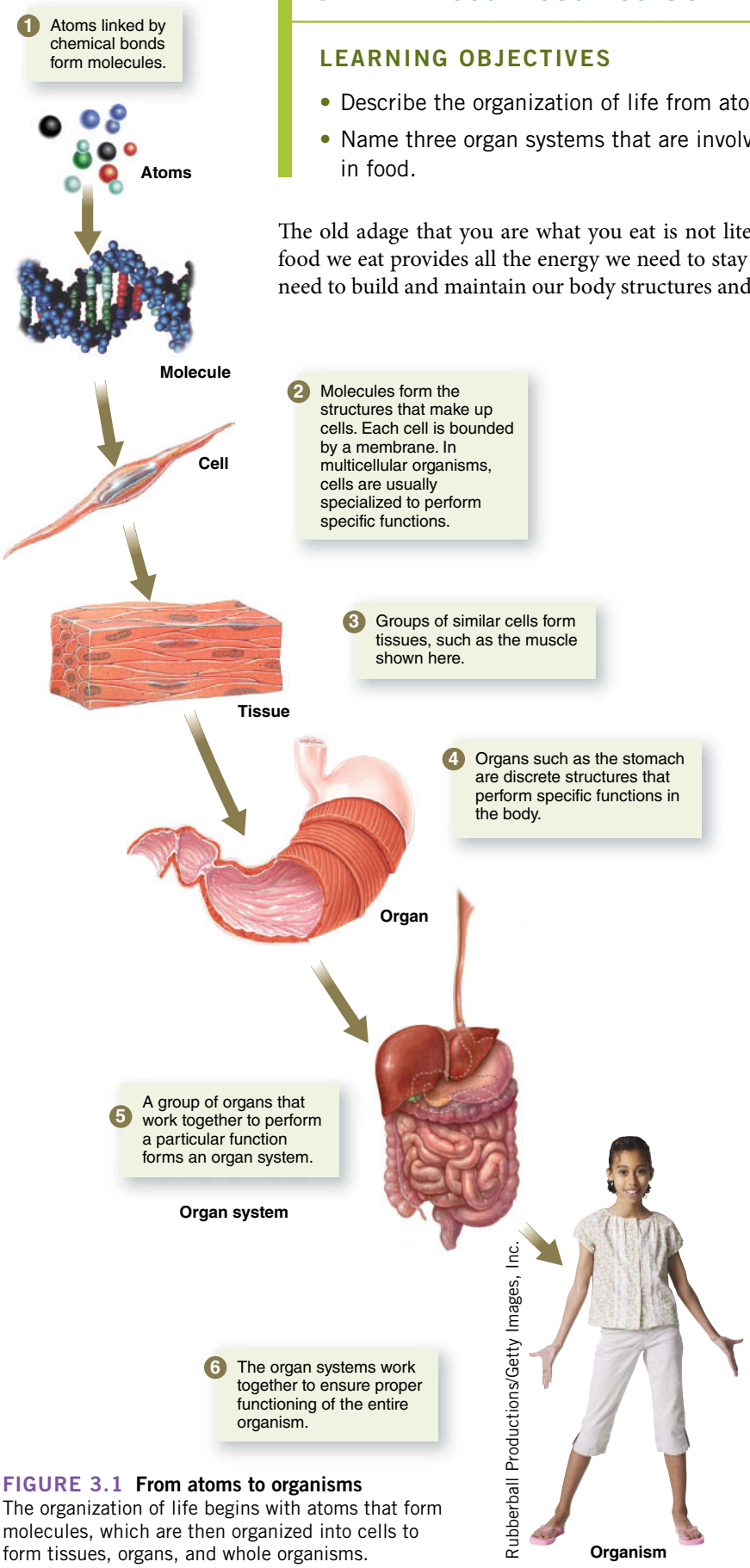


FIGURE 3.1 From atoms to organisms
The organization of life begins with atoms that form molecules, which are then organized into cells to form tissues, organs, and whole organisms.

Atoms Form Molecules

To be useful to us, the food we eat must be broken into smaller components, absorbed into the body, and then converted into forms that can be used. Our bodies and the food we eat, like all matter on Earth, are made of units called *atoms*. Atoms cannot be further broken down by chemical means. Atoms of different elements have different characteristics. Carbon, hydrogen, oxygen, and nitrogen are the most abundant elements in our bodies and in the foods we eat. These atoms can be linked by forces called **chemical bonds** to form **molecules** (Figure 3.1 and online Appendix K). The chemistry of all life on Earth is based on organic molecules, which are those that contain carbon bonded to hydrogen. As discussed in Chapter 1, carbohydrates, lipids, proteins, and vitamins are nutrient classes that are made up of organic molecules, whereas water and minerals are inorganic nutrients because they do not contain carbon–hydrogen bonds.

Cells Form Tissues and Organs

In any living system, molecules are organized into structures that form **cells**, the smallest unit of life. Cells of similar structure and function are organized into tissues. The human body contains four types of tissue: muscle, nerve, epithelial, and connective. These tissues are organized in varying combinations into **organs**, which are discrete structures that perform specialized functions in the body (see Figure 3.1). The stomach is an example of an organ; it contains all four types of tissue.

Organs Cooperate as Organ Systems

Most organs do not function alone but are part of a group of cooperative organs called an *organ system*. The organ systems in humans are described in Table 3.1.

TABLE 3.1 Organ Systems and Their Functions

Organ system	What it includes	What it does
Nervous	Nerves, sense organs, brain, and spinal cord	Responds to stimuli from the external and internal environments; conducts impulses to activate muscles and glands; integrates activities of other systems.
Respiratory	Lungs, trachea, and air passageways	Supplies the blood with oxygen and removes carbon dioxide.
Urinary	Kidneys, bladder, and associated structures	Eliminates wastes and regulates the balance of water, electrolytes, and acid in the blood.
Reproductive	Testes, ovaries, and associated structures	Produces offspring.
Cardiovascular/circulatory	Heart and blood vessels	Transports blood, which carries oxygen, nutrients, and wastes.
Lymphatic/ immune	Lymph and lymph structures, white blood cells	Defends against foreign invaders; picks up fluid leaked from blood vessels; transports fat-soluble nutrients.
Muscular	Skeletal muscles	Provides movement and structure.
Skeletal	Bones and joints	Protects and supports the body; provides a framework for the muscles to use for movement.
Endocrine	Pituitary, adrenal, thyroid,pancreas, and other ductless glands	Secretes hormones that regulate processes such as growth, reproduction, and nutrient use.
Integumentary	Skin, hair, nails, and sweat glands	Covers and protects the body; helps control body temperature.
Digestive	Mouth, pharynx, esophagus, stomach, intestines, pancreas, liver, and gallbladder	Ingests and digests food; absorbs nutrients into the blood; eliminates unabsorbed food residues.

An organ may be part of more than one organ system. For example, the pancreas is part of the endocrine system as well as the digestive system. Organ systems work together to support the entire organism.

The digestive system is the organ system primarily responsible for the movement of nutrients into the body; however, several other organ systems are also important in using nutrients. The endocrine system secretes **hormones** that help regulate food intake and the function of digestive organs. The nervous system aids in digestion by sending nerve signals that help control the passage of food through the digestive tract. Once absorbed, nutrients are transported to individual cells by the cardiovascular system. The body's urinary, respiratory, and integumentary systems allow the elimination of metabolic waste products.

chemical bond Force that holds atoms together.

molecule A group of two or more atoms of the same or different elements bonded together.

cell The basic structural and functional unit of living things.

organ A discrete structure composed of more than one tissue that performs a specialized function.

hormone Chemical messenger that is produced in one location, released into the blood, and elicits responses at other locations in the body.

3.2 The Digestive System

LEARNING OBJECTIVES

- Define *digestion* and *absorption*.
- Explain the roles of mucus, enzymes, nerves, and hormones in digestion.

The digestive system provides two major functions: **digestion** and **absorption**. Most food must be digested in order for the nutrients it contains to be absorbed into the body. When you eat a taco, for example, the tortilla, meat, cheese, lettuce, and tomato are broken apart, releasing the nutrients and other food components they contain. Water, vitamins, and minerals are absorbed without being broken into smaller units, but proteins, carbohydrates, and fats must be digested further. Proteins are broken down into amino acids, most of the carbohydrate is broken down into sugars, and most fats are digested to yield fatty acids and other digestive products. The sugars, amino acids, and fatty acids can then be absorbed into the body. The fiber in whole grains, fruits, and vegetables cannot be digested and therefore is not absorbed from the digestive tract into the body. It and other unabsorbed substances pass through the digestive tract and are eliminated in **feces**.

digestion The process of breaking food into components small enough to be absorbed into the body.

absorption The process of taking substances into the interior of the body.

feces Body waste, including unabsorbed food residue, bacteria, mucus, and dead cells, which is excreted from the gastrointestinal tract by passing through the anus.

Organs of the Digestive System

gastrointestinal tract A hollow tube consisting of the mouth, pharynx, esophagus, stomach, small intestine, and large intestine, in which digestion and absorption of nutrients occurs.

The digestive system consists of the **gastrointestinal tract** and accessory organs (Figure 3.2A). The gastrointestinal tract is a hollow tube, about 30 feet in length, that runs from the mouth, where food enters, to the anus, where waste from that food leaves the body. It is also called the GI tract, gut, digestive tract, intestinal tract, and alimentary canal. The organs of the gastrointestinal tract include the mouth, pharynx, esophagus, stomach, small intestine, and large intestine. The inside of the tube that these organs form is called the *lumen* (Figure 3.2B). Food within the lumen of the gastrointestinal tract has not been absorbed and is therefore technically still outside the body. When you swallow something that cannot be digested, such as an apple seed, it passes through your digestive tract and exits in the feces without ever being broken down or entering your blood or cells. Only after substances have been absorbed into the cells that line the intestine can they be said to be "inside" the body.

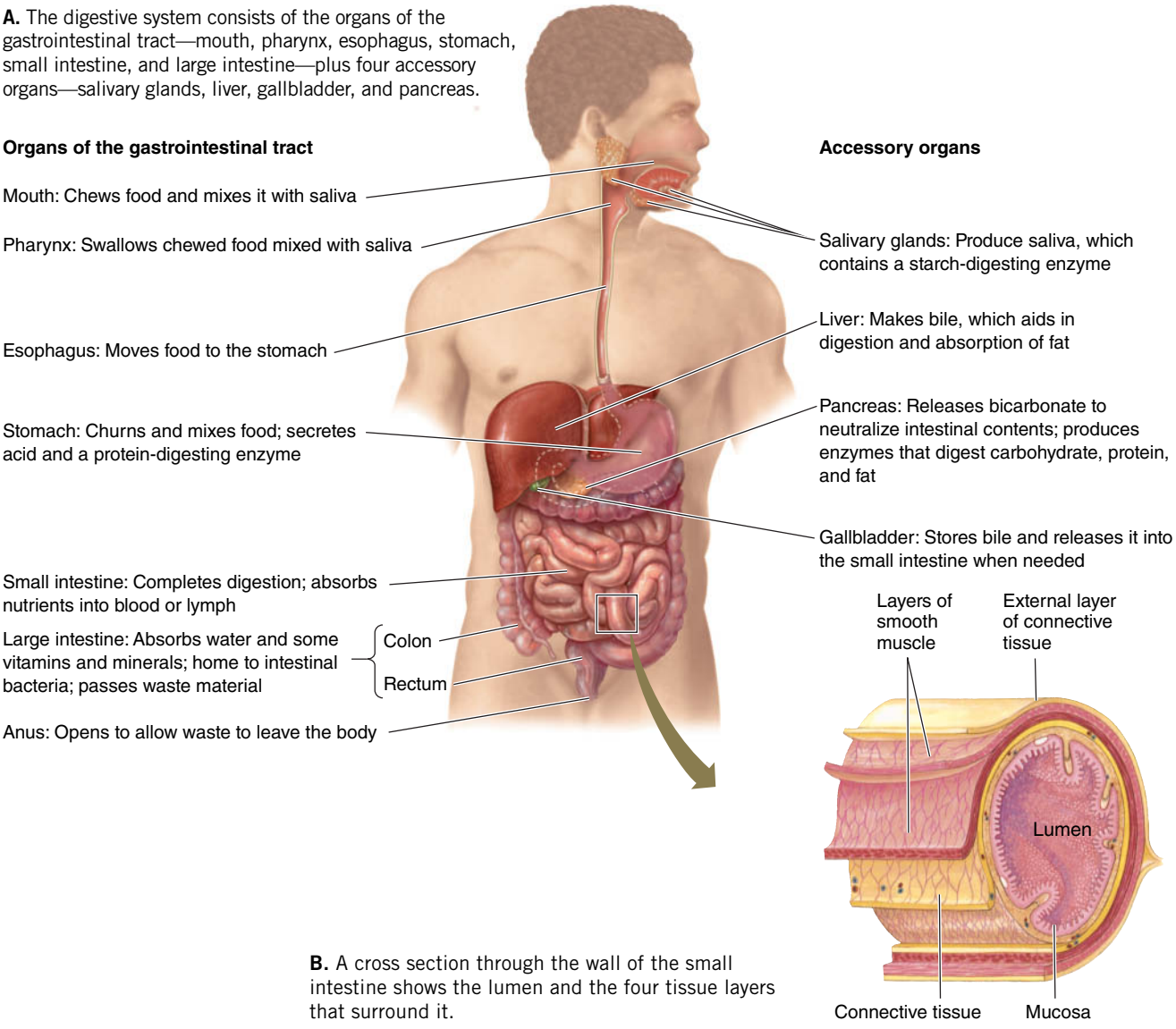
transit time The time between the ingestion of food and the elimination of the solid waste from that food.

How Long Is Food in the GI Tract?

The amount of time it takes for food and its waste products to pass the length of the GI tract from mouth to anus is referred to as **transit time**. In a healthy adult, transit time is about 24 to 72 hours. It is affected by the composition of the diet, physical activity, emotions, medications, and illnesses. To measure transit time, researchers add a nonabsorbable dye to a meal and measure the time between consumption of the dye and its appearance in the feces. The shorter the transit time, the more rapidly material is passing through the digestive tract.

FIGURE 3.2 Structure of the digestive system

A. The digestive system consists of the organs of the gastrointestinal tract—mouth, pharynx, esophagus, stomach, small intestine, and large intestine—plus four accessory organs—salivary glands, liver, gallbladder, and pancreas.



B. A cross section through the wall of the small intestine shows the lumen and the four tissue layers that surround it.

Structure of the Gut Wall The wall of the GI tract contains four layers of tissue (see Figure 3.2B). Lining the lumen is the **mucosa**, a layer of epithelial cells called *mucosal cells* that serves as a protective barrier and is responsible for some digestion and for the absorption of the end products of digestion. The cells of the mucosa are in direct contact with churning food and harsh digestive secretions. Therefore, these cells have a short life span—only about two to five days. When these cells die, they are sloughed off into the lumen, where some components are digested and absorbed and the remainder are excreted in the feces. Because mucosal cells reproduce rapidly, the mucosa has high nutrient requirements and is therefore one of the first parts of the body to be affected by nutrient deficiencies.

Surrounding the mucosa is a layer of connective tissue containing nerves and blood vessels. This layer provides support, delivers nutrients to the mucosa, and provides the nerve signals that control secretions and muscle contractions. Layers of smooth muscle—the type over which we do not have voluntary control—surround the connective tissue. The contraction of smooth muscles mixes food, breaks it into smaller particles, and propels it through the digestive tract. The final, external layer is also made up of connective tissue and provides support and protection.

mucosa The layer of epithelial tissue lining the GI tract and other body cavities.

mucus A viscous fluid secreted by glands in the GI tract and other parts of the body. It acts to lubricate, moisten, and protect cells from harsh environments.

enzyme A protein molecule that accelerates the rate of a chemical reaction without itself being changed.

Digestive Secretions

Digestion inside the lumen of the GI tract is aided by digestive secretions. One of these substances is **mucus**, a viscous material produced by cells in the mucosal lining of the gut. Mucus moistens, lubricates, and protects the digestive tract. **Enzymes**, another component of digestive system secretions, are protein molecules that speed up chemical reactions without themselves being consumed or changed by the reactions (Figure 3.3). In digestion, enzymes accelerate the breakdown of nutrients. Different enzymes are needed to break down different nutrients. For example, an enzyme that digests carbohydrate has no effect on fat, and one that digests fat has no effect on carbohydrate. Digestive enzymes and their actions are summarized in Table 3.2.

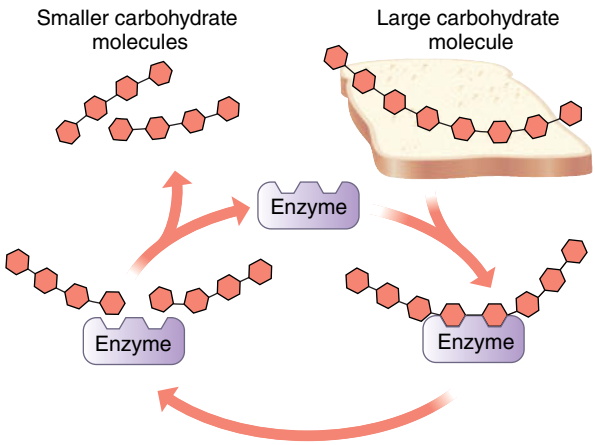


FIGURE 3.3 Enzymes
Enzymes speed up chemical reactions without themselves being altered by the reaction. In this example, the enzyme amylase helps break a large carbohydrate molecule (a starch molecule from the bread) into two smaller ones.

TABLE 3.2 Digestive Enzyme Functions

Enzyme	Where it comes from	Where it works	What it does
Salivary amylase	Salivary glands	Mouth	Breaks starch (a large carbohydrate molecule) into smaller carbohydrate molecules.
Lingual lipase	Lingual glands in tongue	Mouth	Breaks triglycerides into monoglycerides, fatty acids, and glycerol.
Pepsin	Stomach	Stomach	Breaks proteins into shorter polypeptides
Gastric lipase			Breaks triglycerides into monoglycerides, fatty acids, and glycerol.
Trypsin	Pancreas	Small intestine	Breaks proteins into shorter polypeptides.
Chymotrypsin			Breaks proteins into shorter polypeptides.
Carboxypeptidase			Breaks polypeptides into shorter polypeptides and amino acids.
Pancreatic lipase			Breaks triglycerides into monoglycerides, fatty acids, and glycerol.
Pancreatic amylase			Breaks starch into shorter glucose chains and maltose.
Aminopeptidase and dipeptidase	Small intestine	Small intestine	Breaks polypeptides into shorter polypeptides and amino acids.
Sucrase			Breaks sucrose into glucose and fructose.
Lactase			Breaks lactose into glucose and galactose.
Maltase			Breaks maltose into glucose.
Dextrinase			Breaks short chains of glucose into individual glucose molecules.

TABLE 3.3 Digestive Hormone Functions

Hormone	Where it comes from	What it does
Gastrin	Stomach mucosa	Stimulates secretion of hydrochloric acid (HCl) and pepsinogen by gastric glands in the stomach and increases gastric motility and emptying.
Ghrelin	Stomach	Stimulates appetite, increases gastric emptying.
Secretin	Duodenal mucosa	Inhibits gastric secretion and motility; increases output of water and bicarbonate from the pancreas; increases bile output from the liver.
Cholecystokinin (CCK)		Stimulates contraction of the gallbladder to expel bile; increases output of enzyme-rich pancreatic juice; slows stomach emptying and contributes to satiety.
Gastric inhibitory peptide		Inhibits gastric secretion and motility.

How Gastrointestinal Activity Is Regulated

Nerve signals help regulate activity in the GI tract. The sight and smell of food, as well as the presence of food in the gut, stimulate nerves throughout the GI tract. For example, food in the mouth can trigger a nerve impulse that signals the stomach to prepare itself for the arrival of food. Nerve signals cause muscle contractions that churn, mix, and propel food through the gut at a rate that allows optimal absorption of nutrients. Nerve signals also stimulate or inhibit digestive secretions. For example, food in the mouth stimulates digestive secretions in the stomach. After food has passed through a section of the digestive tract, digestive secretions decrease and muscular activity slows to conserve energy and resources for other body processes. The nerves in the GI tract also communicate with the brain so digestive activity can be coordinated with other body needs.

Activity in the digestive tract is also regulated by hormones released into the bloodstream. Hormones that affect gastrointestinal function are produced both by cells lining the digestive tract and by a number of accessory organs. Hormonal signals help prepare different parts of the gut for the arrival of food and thus regulate the digestion of nutrients and the rate that food moves through the system. Some of the hormones released by the GI tract and their functions are summarized in Table 3.3.

3.3 Digestion and Absorption

LEARNING OBJECTIVES

- Describe what happens in each of the organs of the gastrointestinal tract.
- Discuss factors that influence how quickly food moves through the gastrointestinal tract.
- Explain how the structure of the small intestine enhances its function.
- Distinguish simple diffusion, osmosis, facilitated diffusion, and active transport.

Imagine the smell of freshly baked cookies. Is your mouth watering? You don't even need to put food in your mouth for activity to begin in the digestive tract. Sensory input such as the sight and smell of the cookies, and even just the thought of food, may make your mouth water and your stomach rumble and begin to secrete digestive substances. This cephalic (pertaining to the head) response occurs when the nervous system signals the digestive system to ready itself for a meal. It can occur even when the body is not in need of food. In order for food to be used by the body, however, you need to do more than smell your meal. The food must be consumed and digested, and the nutrients must be absorbed and transported to the body's cells. This involves the combined functions of all the organs of the digestive system, as well as the help of some other organ systems.

The Mouth

The mouth is the entry point for food into the digestive tract. Here, food is tasted and the mechanical breakdown and chemical digestion of food begin. The presence of food in the mouth stimulates the flow of **saliva** from the salivary glands located internally at the sides of the face and immediately below and in front of the ears (see Figure 3.2A). Saliva plays many roles: It moistens the food so that it can easily be tasted and swallowed; it begins the enzymatic digestion of starch; it cleanses the mouth and protects teeth from decay; and it lubricates the upper GI tract. By moistening food, saliva helps us taste because molecules from the food dissolve in the saliva and are carried to the taste buds, most of which are located on the tongue. Signals from the taste buds, along with the aroma of food, allow us to enjoy the taste of the food we eat. Saliva begins the chemical digestion of carbohydrate because it contains the enzyme **salivary amylase**. Salivary amylase can break the long sugar chains of starch in foods like bread and potatoes into shorter chains of sugars (see Figure 3.3). Saliva also protects against tooth decay because it helps wash away food particles and it contains **lysozyme**—an enzyme that inhibits the growth of bacteria, some of which contribute to tooth decay (see Chapter 4).

Chewing food begins the mechanical aspect of digestion. Adult humans have 32 teeth, specialized for biting, tearing, grinding, and crushing foods. Chewing breaks food into small pieces. This makes the food easier to swallow and increases the surface area in contact with digestive juices. The tongue helps mix food with saliva and aids chewing by constantly repositioning food between the teeth. Chewing also breaks apart fiber, which traps nutrients in some foods. If the fiber is not broken apart, some nutrients cannot be absorbed. For example, if the fibrous skin of a raisin is not broken open by the teeth, the nutrients within the raisin will remain inaccessible and the raisin will travel undigested through the intestines and be eliminated in the feces.

saliva A watery fluid produced and secreted into the mouth by the salivary glands. It contains lubricants, enzymes, and other substances.

salivary amylase An enzyme secreted by the salivary glands that breaks down starch.

lysozyme An enzyme in saliva, tears, and sweat that is capable of destroying certain types of bacteria.

pharynx A funnel-shaped opening that connects the nasal passages and mouth to the respiratory passages and esophagus. It is a common passageway for food and air and is responsible for swallowing.

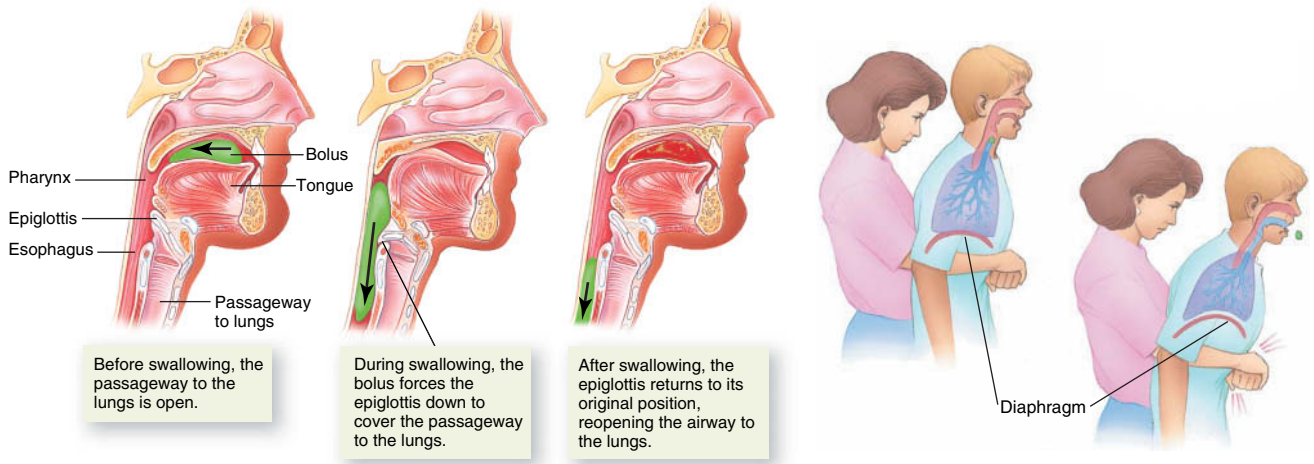
epiglottis A piece of elastic connective tissue at the back of the throat that covers the opening of the passageway to the lungs during swallowing.

The Pharynx

The tongue initiates swallowing by moving the rounded mass, or bolus, of chewed food mixed with saliva back toward the **pharynx**. The pharynx is shared by the digestive tract and the respiratory tract: Food and liquid pass through the pharynx on their way to the stomach, and air passes here on its way to and from the lungs. We are able to start the muscular contractions of swallowing by choice, but once initiated swallowing becomes involuntary and proceeds under the control of nerves.

During swallowing, the air passages are blocked by a valve-like flap of tissue called the **epiglottis**, which ensures that the bolus of food passes to the stomach, not the lungs (Figure 3.4A). Sometimes food can pass into an upper air passageway. It is usually dislodged with a cough, but if it becomes stuck it can block the flow of air and cause choking. A quick response is required to

FIGURE 3.4 Keeping food out of the airways



A. When a bolus of food is swallowed, it pushes the epiglottis down over the opening to the air passageways.

B. If food becomes lodged in the passageway leading to the lungs, it can block the flow of air. The Heimlich maneuver, which involves a series of thrusts directed upward from under the diaphragm (the muscle separating the chest and abdominal cavities), forces air out of the lungs, blowing the lodged food out of the air passageway.

save the life of a person whose airway is completely blocked. The Heimlich maneuver, which forces air out of the lungs by using a sudden application of pressure just below the diaphragm, can blow an object out of the blocked air passage (Figure 3.4B).

The Esophagus

esophagus A portion of the GI tract that extends from the pharynx to the stomach.

peristalsis Coordinated muscular contractions that move food through the GI tract.

The **esophagus** is a tube that passes through the diaphragm, a muscular wall separating the abdominal cavity from the chest cavity where the lungs are located, to connect the pharynx and stomach. In the esophagus the bolus of food is moved along by rhythmic contractions of the smooth muscles, called **peristalsis** (Figure 3.5). Peristalsis is like an ocean wave that moves through the muscle, producing a narrowing in the lumen that pushes food and fluid in front of it. It takes only about four to eight seconds for solid food to move from the pharynx down the esophagus to the stomach, and even less time for liquids to make the trip. The peristaltic waves in the esophagus are so powerful that food and fluids will reach your stomach even if you are upside down. This contractile movement, which is controlled automatically by the nervous system, occurs throughout the GI tract, pushing the food bolus along from the pharynx through the large intestine.

sphincter A muscular valve that helps control the flow of materials in the GI tract.

To move from the esophagus into the stomach, food must pass through a **sphincter**, a muscle that encircles the tube of the digestive tract and acts as a valve. When the muscle contracts, the valve is closed. The gastroesophageal sphincter, also called the cardiac or lower esophageal sphincter, relaxes reflexively just before a peristaltic wave reaches it, allowing food to enter the stomach (see Figure 3.5). The gastroesophageal sphincter normally prevents food from moving back out of the stomach. Occasionally, however, materials do pass out of the stomach through this valve. Heartburn occurs when some of the acidic stomach contents leak up and out of the stomach into the esophagus, causing a burning sensation. Vomiting is the result of a reverse peristaltic wave that causes the sphincter to relax and allow the food to pass upward out of the stomach toward the mouth.

The Stomach

The stomach is an expanded portion of the GI tract that serves as a temporary storage place for food. While held in the stomach, the bolus is mashed and mixed with highly acidic stomach

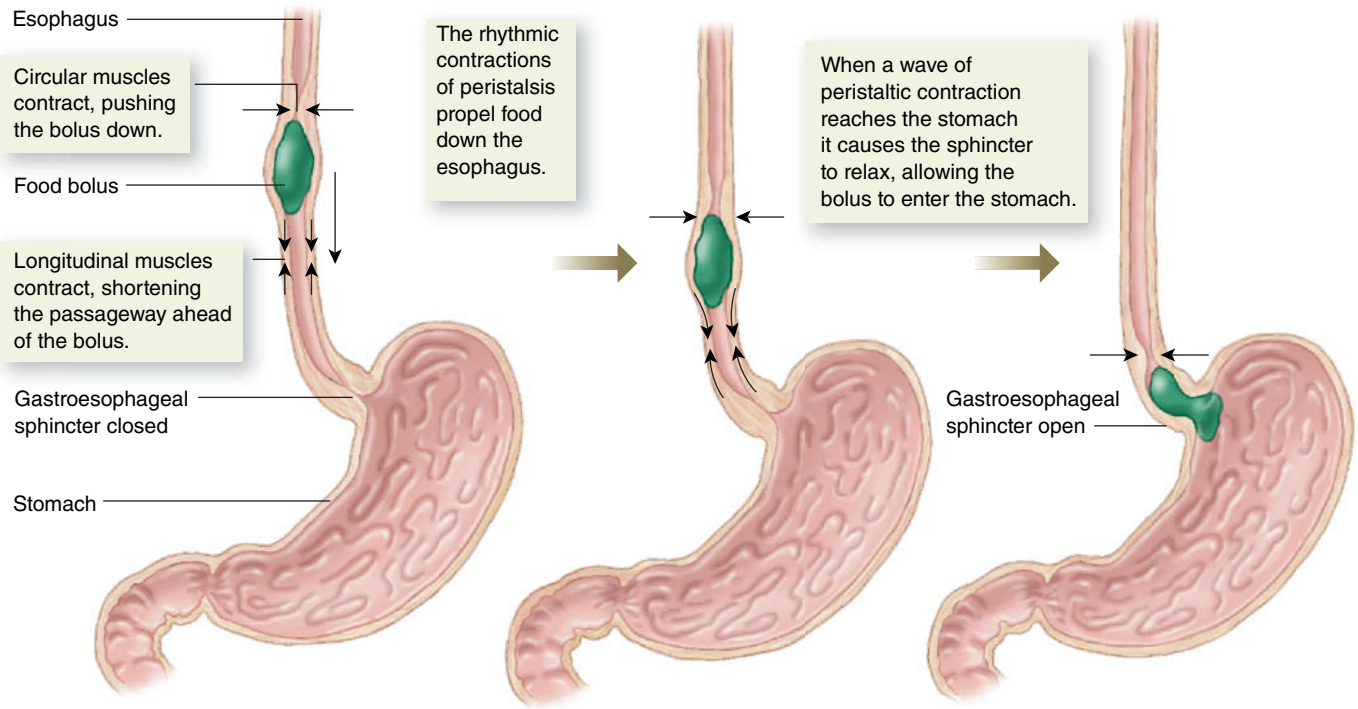
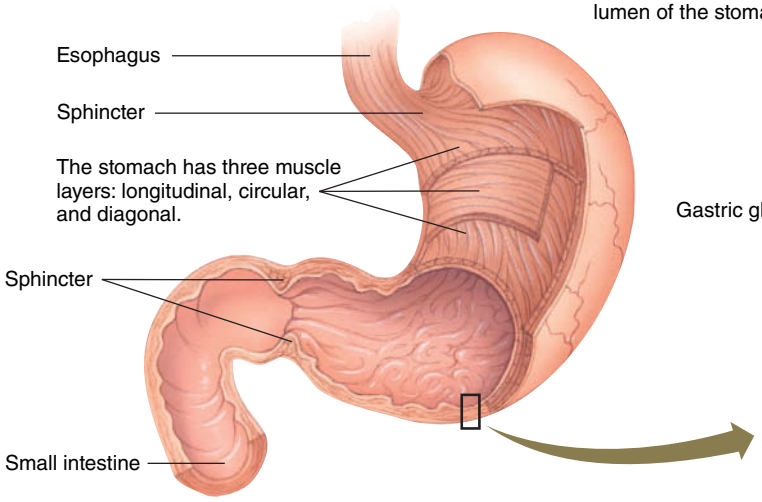
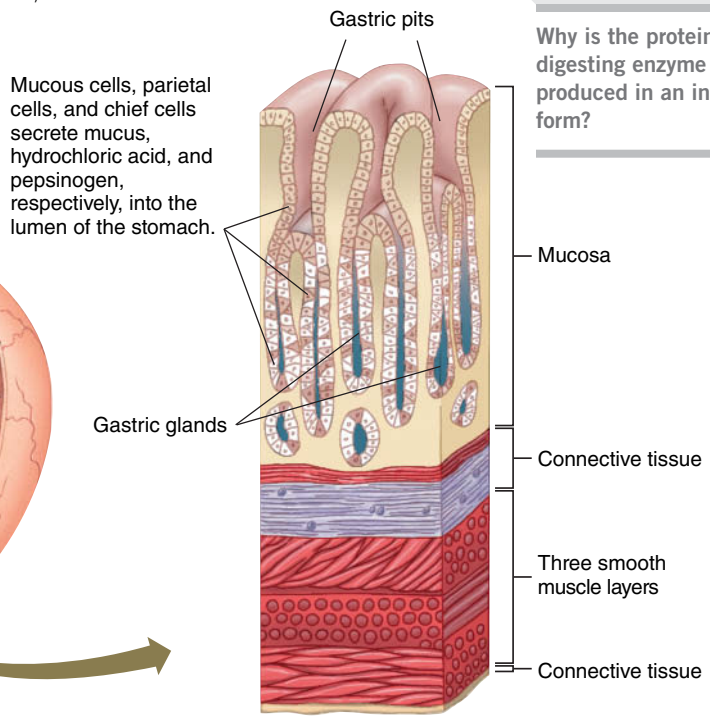


FIGURE 3.5 Peristalsis propels food
The food we swallow is pushed along by the rhythmic muscular contractions of peristalsis. Food enters the stomach in response to the opening and closing of the gastroesophageal sphincter, located where the esophagus meets the stomach.

FIGURE 3.6 Structure of the stomach

A. The stomach wall contains three layers of smooth muscle, which contract powerfully to mix food.





B. The lining of the stomach is dotted with gastric pits. Inside these pits are the gastric glands, made up of different types of cells that produce the components of gastric juice.

THINK CRITICALLY

Why is the protein-digesting enzyme pepsin produced in an inactive form?

secretions to form a semiliquid food mass called **chyme**. Some digestion takes place in the stomach but, with the exception of some water, alcohol, and a few drugs, including aspirin and acetaminophen (Tylenol), very little absorption occurs here.

chyme A mixture of partially digested food and stomach secretions.

How the Structure of the Stomach Supports Its Function The stomach walls are thicker and have more muscle than other segments of the GI tract. Two layers of muscle, one running longitudinally down the tract and one running around it, surround most of the GI tract. The stomach has an additional layer that circles it diagonally, allowing for powerful contractions that thoroughly churn and mix the stomach contents (Figure 3.6A).

The lining of the stomach is interrupted by millions of tiny openings called gastric pits. At the bottom of these pits are the gastric glands. A number of different types of cells cover the surface of the stomach and extend into the gastric pits and glands (Figure 3.6B). Some secrete substances into the stomach. These stomach secretions are collectively referred to as *gastric juice*. Other cells in the gastric glands secrete a variety of hormones and hormone-like compounds into the blood.

What Is in Gastric Juice? Gastric juice is a mixture of water, mucus, hydrochloric acid, and an inactive enzyme called **pepsinogen**. Hydrochloric acid, produced by parietal cells, acidifies the stomach contents and as a result kills most bacteria present in food. Parietal cells also produce intrinsic factor, which is needed for the absorption of vitamin B_{12} (see Chapter 8). Pepsinogen is produced by chief cells. It is an inactive form of the protein-digesting enzyme **pepsin**, which breaks the chains of amino acids in proteins, called *polypeptides*, into shorter polypeptides. Pepsin is secreted in an inactive form so that it will not damage the gastric glands that produce it. It is activated by hydrochloric acid when it enters the stomach. Pepsin functions best in the acidic environment of the stomach. This acidic environment stops the function of salivary amylase. Therefore, the digestion of starch from foods such as bread and potatoes stops in the stomach, and digestion of the protein from foods such as meat, milk, and legumes begins. The protein of the stomach wall is protected from the acid and pepsin by a thick layer of mucus.

pepsinogen An inactive protein-digesting enzyme produced by gastric glands and activated to pepsin by acid in the stomach.

pepsin A protein-digesting enzyme produced by the gastric glands. It is secreted in the gastric juice in an inactive form and activated by acid in the stomach.

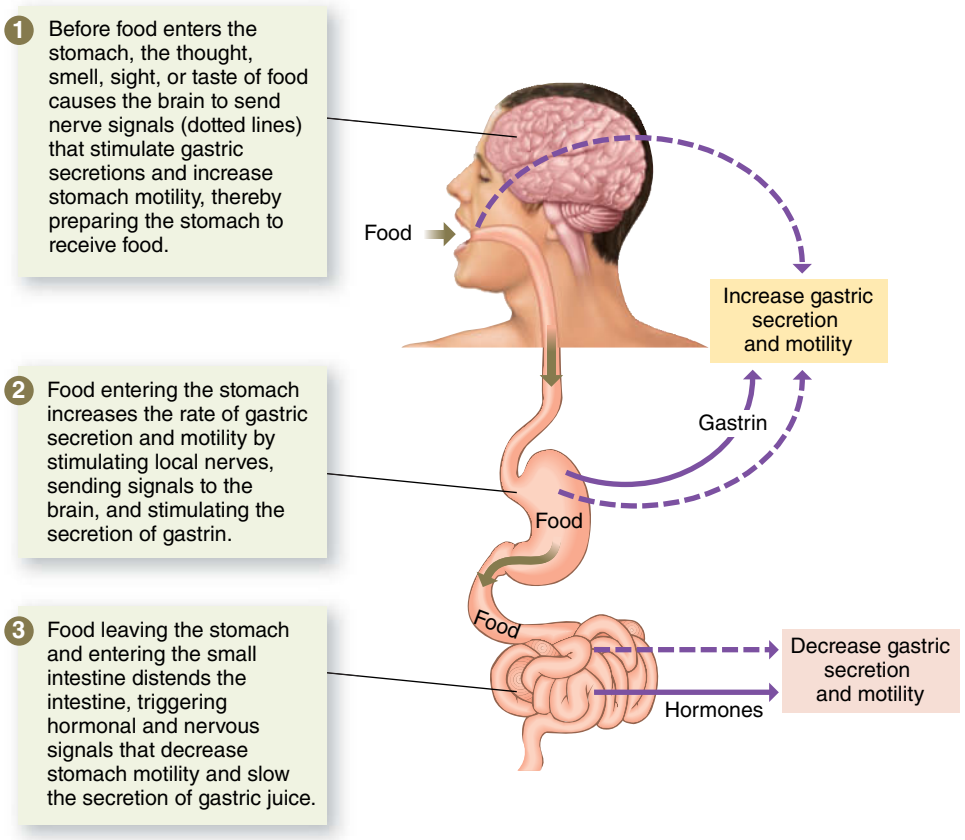


FIGURE 3.7 Regulation of stomach motility and secretion
Stomach activity is affected by food that has not yet reached the stomach, by food that is in the stomach, and by food that has left the stomach.

How Stomach Activity Is Regulated How much your stomach churns, how much gastric juice is released, and how fast material empties out of the stomach are regulated by signals from both nerves and hormones. These signals originate from three different sites—the brain, the stomach, and the small intestine (Figure 3.7). The thought, smell, sight, or taste of food causes the brain to send nerve signals that stimulate gastric motility and secretion, preparing the stomach to receive food. Food entering the stomach further stimulates the release of gastric secretions and an increase in motility. It does this by stretching local nerves, sending signals to the brain, and promoting the secretion of the hormone **gastrin**. Gastrin then triggers the release of gastric juice and increases stomach motility.

gastrin A hormone secreted by the stomach mucosa that stimulates the secretion of gastric juice.

As chyme moves out of the stomach, it passes through the pyloric sphincter, which helps regulate the rate at which food empties from the stomach. Chyme entering the small intestine triggers hormonal and nervous signals that can decrease stomach motility and secretions and slow stomach emptying. This ensures that the amount of chyme entering the small intestine does not exceed the ability of the intestine to process it. Chyme normally leaves the stomach in two to six hours, but this rate is affected by the size and composition of the meal. A large meal will take longer to leave the stomach than a small meal. Liquids empty quickly, but solids linger until they are well mixed with gastric juice and are liquefied; hence, a liquid meal leaves the stomach more quickly than a solid meal.

The nutritional composition of a meal also affects how long it stays in the stomach. A high-fat meal will stay in the stomach the longest because fat entering the small intestine causes the release of hormones that slow GI motility, thus slowing stomach emptying. A meal that is primarily protein will leave more quickly, and a meal of mostly carbohydrate will leave the fastest. The reason you are often ready to eat again soon after a dinner of vegetables and rice is that this high-carbohydrate, low-fat meal leaves the stomach rapidly (Figure 3.8).

© OlgaMiltsova/iStockphoto

FIGURE 3.8 Meal composition affects hunger and satiety
What you choose for breakfast can affect when you become hungry for lunch. Toast and coffee will leave your stomach quickly. A larger meal with more protein and fat such as the bacon, eggs, and buttered toast shown here leaves the stomach more slowly, keeping you full longer.

Other factors such as exercise and emotions also affect gastric emptying. Sadness and fear tend to slow emptying, while aggression tends to increase gastric motility and speed emptying. Exercise will delay stomach emptying because the body directs its resources to the exercising muscles.

The Small Intestine

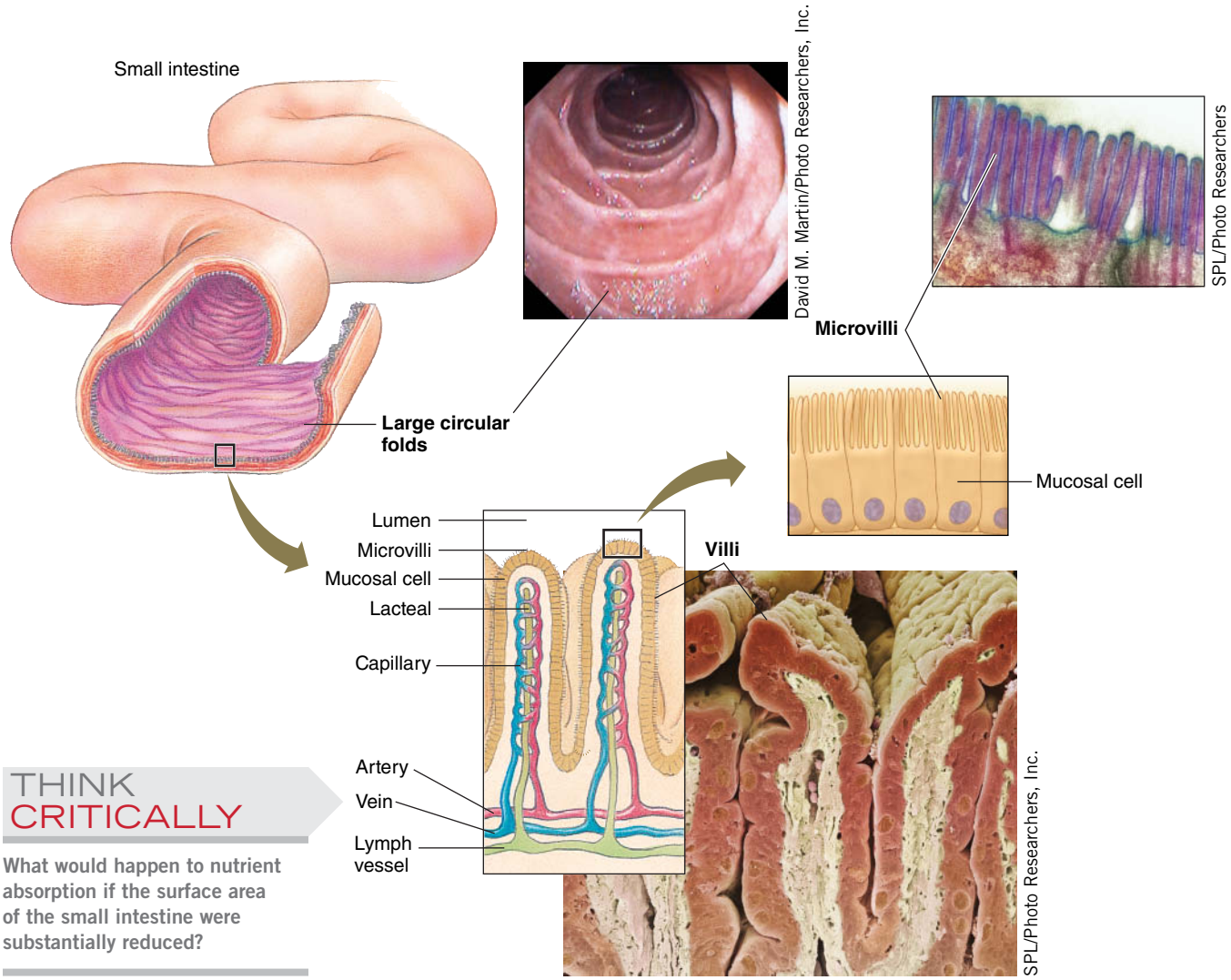
The small intestine is the main site of digestion of food and absorption of nutrients. It is a narrow tube about 20 feet in length. It is divided into three segments. The first 12 inches are the duodenum, the next 8 feet are the jejunum, and the last 11 feet are the ileum.

How the Structure of the Small Intestine Maximizes Function The structure of the small intestine maximizes the absorption of nutrients. In addition to its length, the small intestine has three other features that increase the area of its absorptive surface (Figure 3.9). First, the intestinal wall has large circular folds, which increase the surface area in contact with nutrients. Second, its entire inner surface is covered with finger-like projections called **villi** (singular **villus**). And last, the mucosal cells on the surface of each of these villi are covered with tiny **microvilli**, often referred to as the **brush border**. Within each villus are a blood vessel and a lymph vessel, called a **lacteal**; these are located only one cell layer away from

villi (villus) Finger-like protrusions of the lining of the small intestine that participate in the digestion and absorption of nutrients.

microvilli or **brush border** Minute brush-like projections on the mucosal cell membrane that increase the absorptive surface area in the small intestine and contain some digestive enzymes.

lacteal A small lymph vessel in the intestine that absorbs and transports the products of fat digestion.



THINK CRITICALLY

What would happen to nutrient absorption if the surface area of the small intestine were substantially reduced?

FIGURE 3.9 Structure of the small intestine
The small intestine contains large circular folds, finger-like projections called *villi*, and tiny projections, called *microvilli*, all of which increase the absorptive surface area. Together these features provide a surface area that is about the size of a tennis court (250 square meters or 2700 square feet).

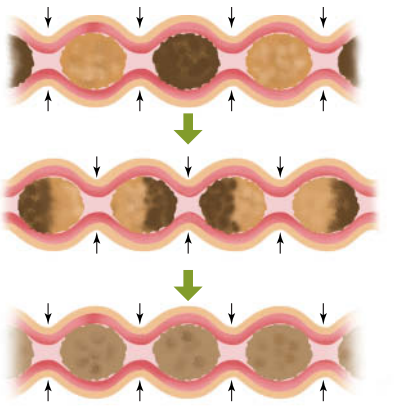


FIGURE 3.10 Segmentation
Segmentation involves alternating contraction and relaxation of the circular muscles of the small intestine. This movement mixes food with intestinal juices and brings it in contact with the intestinal wall.

the nutrients in the intestinal lumen. Nutrients must cross the mucosal cell layer to reach the bloodstream or lymphatic system for delivery to the tissues of the body.

Motility and Secretions in the Small Intestine Chyme is propelled through the small intestine by peristalsis, and the mixing of chyme with digestive secretions is aided in the small intestine by rhythmic local constrictions called **segmentation** (Figure 3.10). Segmentation also enhances absorption by repeatedly moving chyme over the surface of the intestinal mucosa.

The cells of the small intestine produce some digestive enzymes as well as a watery mucus-containing fluid called *intestinal juice* that aids in absorption. However, normal digestion and absorption in the small intestine also require secretions from the pancreas and gallbladder. The pancreas secretes pancreatic juice, which contains both bicarbonate ions and digestive enzymes. The bicarbonate ions neutralize the acid in chyme, making the environment in the small intestine neutral rather than acidic as it is in the stomach. This neutrality allows enzymes from the pancreas and small intestine to function. The enzyme **pancreatic amylase** continues the job of breaking starch into sugars that was started in the mouth by salivary amylase. Pancreatic **proteases**, including trypsin and chymotrypsin (see Table 3.2), continue to break proteins into shorter and shorter chains of amino acids, and pancreatic fat-digesting enzymes, called **lipases**, break triglycerides into fatty acids and other breakdown products. Intestinal digestive enzymes, found attached to or inside the cells lining the small intestine, are involved in the digestion of sugars into single sugar units and the digestion of small polypeptides into single amino acids. The sugars from carbohydrate digestion and the amino acids from protein digestion pass into the blood and are delivered to the liver (Figure 3.11).

segmentation Rhythmic local constrictions of the intestine that mix food with digestive juices and speed absorption by repeatedly moving the food mass over the intestinal wall.

pancreatic amylase Starch-digesting enzyme produced in the pancreas and released into the small intestine.

protease A protein-digesting enzyme.

lipase A fat-digesting enzyme.

The gallbladder stores and secretes **bile**, a fluid containing bile acids and cholesterol that is produced in the liver and is necessary for fat digestion and absorption. Bile secreted into the small intestine mixes with fat and the bile acids help divide the large lipid droplets into smaller globules, allowing lipases to access and digest the fat molecules more efficiently. The bile acids and digested fats then form small droplets that facilitate the absorption of fat into the mucosal cells. Once inside the mucosal cells, the products of fat digestion are incorporated into transport particles. These are absorbed into the lymph before passing into the blood (see Figure 3.11 and Chapter 5).

bile A digestive fluid made in the liver and stored in the gallbladder that is released into the small intestine, where it aids in fat digestion and absorption.

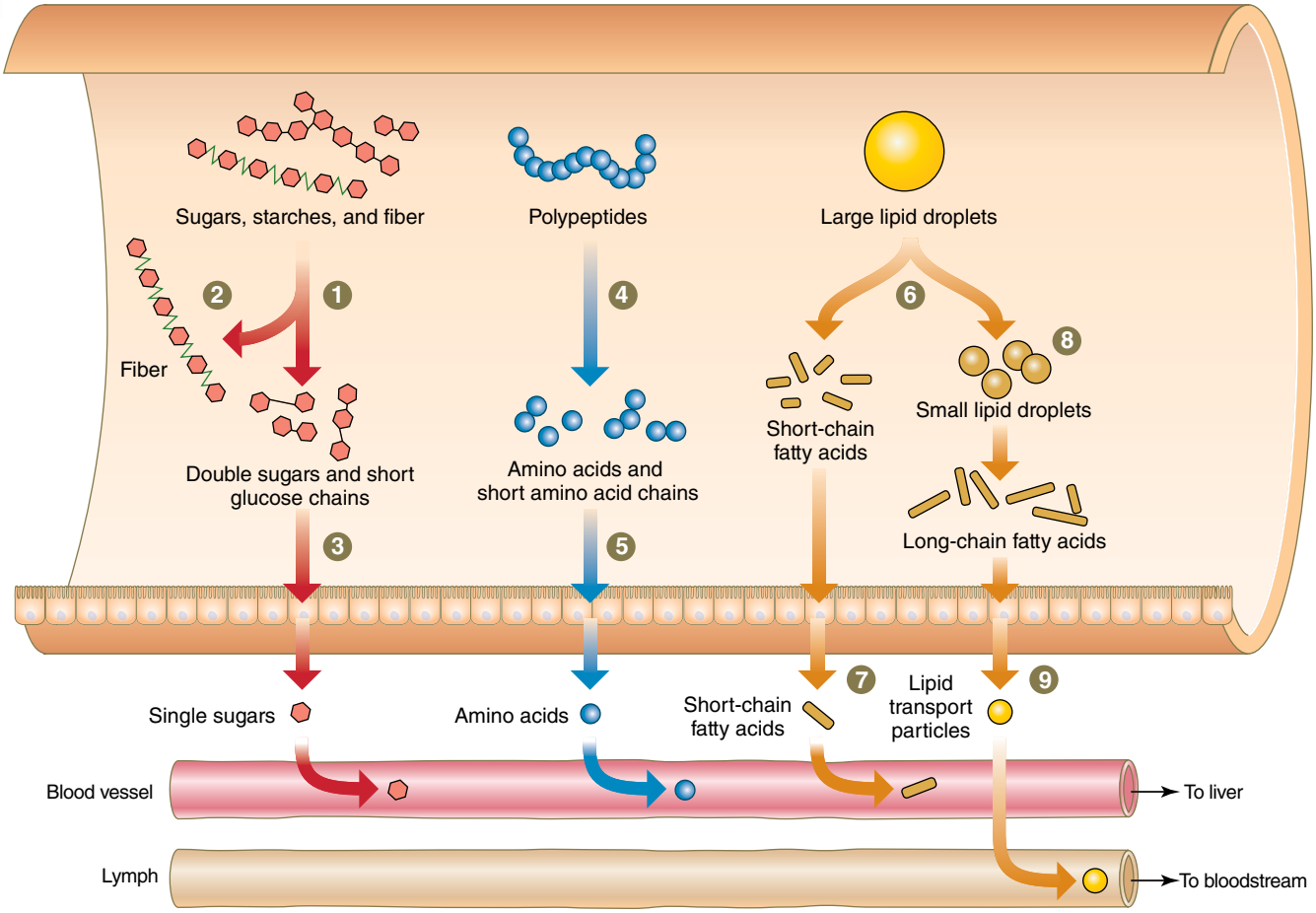
The release of bile and pancreatic juice into the small intestine is controlled by two of the hormones secreted by the mucosal lining of the duodenum (see Table 3.3). Secretin signals the pancreas to secrete pancreatic juice rich in bicarbonate ions and stimulates the liver to secrete bile into the gallbladder. Cholecystokinin (CCK) signals the pancreas to secrete digestive enzymes and causes the gallbladder to contract and release bile into the duodenum.

How Nutrients Are Absorbed The small intestine is the primary site of absorption for water, vitamins, minerals, and the products of carbohydrate, fat, and protein digestion. To be absorbed, these nutrients must pass from the lumen of the GI tract into the mucosal cells lining the tract and then into the blood or lymph. Several different mechanisms are involved in this process. Some rely on diffusion—the net movement of a substance from an area of higher concentration to an area of lower concentration. Nutrients that can pass freely from the lumen of the GI tract across the cell membrane into the mucosal cell can be absorbed by **simple diffusion**. Fat-soluble substances such as vitamin E and fatty acids are absorbed by simple diffusion because they can easily cross the lipid environment of the cell membranes. Water is small, so it also passes freely across cell membranes. The diffusion of water is called **osmosis**. Osmosis results in a net movement of water in a direction that will balance the concentration of dissolved substances on either side of a membrane. For example, if there is a high concentration of sugar in the lumen of the intestine, water will actually move from the mucosal cells into the lumen. As the sugar is absorbed and the concentration of sugar in the lumen decreases, water will move back into the mucosal cells by osmosis. Some nutrients that cannot pass freely across cell membranes are absorbed

simple diffusion The unassisted movement of substances from an area of higher concentration to an area of lower concentration. No energy is required.

osmosis The passive movement of water across a semipermeable membrane in a direction that will equalize the concentration of dissolved substances on both sides.

FIGURE 3.11 Most digestion and absorption occur in the small intestine



1. Pancreatic amylase digests starch to double sugars and short glucose chains.
2. Fiber, which cannot be digested by human enzymes, passes to the large intestine.
3. Enzymes in the microvilli digest double sugars and short glucose chains into single sugars, which are absorbed into the blood.
4. Pancreatic proteases, along with proteases in the microvilli, digest polypeptides into amino acids and short amino acid chains.
5. Amino acids and short amino acid chains are absorbed into the mucosal cells, where they are digested into single amino acids, which pass into the blood.
6. Bile helps divide large fat globules. Pancreatic lipases digest triglycerides.
7. Short-chain fatty acids are absorbed into the mucosal cells and then pass directly into the blood.
8. Long-chain fatty acids and other lipids combine with bile to form small droplets that aid the absorption of fatty acids and other fat-soluble substances into the mucosal cell.
9. Absorbed lipids are incorporated into transport particles that pass into the lymph. They enter the blood without first passing through the liver.

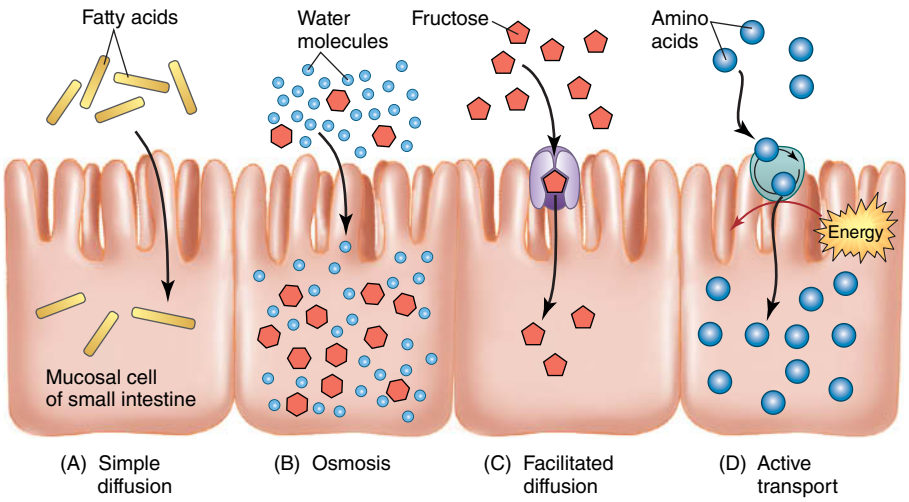
by **facilitated diffusion**, which uses carrier molecules to help substances cross the cell membrane. Even though these nutrients are helped across the cell membrane, they still move from an area of higher concentration to one of lower concentration; the sugar fructose found in fruit is absorbed by facilitated diffusion.

Substances that can't be absorbed by diffusion must enter the body by **active transport**, a process that requires both a carrier molecule and the input of energy. This use of energy allows substances to be transported from an area of lower concentration to an area of higher concentration. The sugar glucose from the breakdown of the starch in a slice of bread and amino acids from protein digestion are absorbed by active transport (Figure 3.12). This allows these nutrients to be absorbed even when they are present in higher concentrations inside the mucosal cells. More specific information about the absorption of the products of carbohydrate, fat, and protein digestion is presented in Chapters 4, 5, and 6, respectively.

facilitated diffusion The assisted movement of substances across a cell membrane from an area of higher concentration to an area of lower concentration. No energy is required.

active transport The transport of substances across a cell membrane with the aid of a carrier molecule and the expenditure of energy. This may occur against a concentration gradient.

FIGURE 3.12 Absorption mechanisms



A. In simple diffusion, substances such as the fatty acids shown here pass freely across the mucosal cell membrane from an area of higher concentration to an area of lower concentration, and no energy is required.

B. Osmosis is the passage of water molecules from an area with a lower concentration of dissolved substances, such as the glucose shown here (red hexagons), to an area with a higher concentration of dissolved substances. No energy is required.

C. Facilitated diffusion is a type of passive diffusion that requires a carrier molecule. Here, fructose molecules move from an area of higher concentration to an area of lower concentration, with the help of a carrier molecule. No energy is required.

D. Active transport requires energy and a carrier molecule and can transport substances from an area of lower concentration to an area of higher concentration. Active transport allows nutrients, such as the amino acids shown here, to be absorbed even when they are present in higher concentrations in the mucosal cell than in the lumen.

The Large Intestine

colon The largest portion of the large intestine.

rectum The portion of the large intestine that connects the colon and anus.

anus The outlet of the rectum through which feces are expelled.

intestinal microbiota or **intestinal microflora** Microorganisms that inhabit the gastrointestinal tract.

Materials not absorbed in the small intestine pass through the ileocecal valve. This sphincter prevents material from the large intestine from reentering the small intestine. The large intestine is about five feet long and is divided into the **colon**, which makes up the majority of the large intestine, and the **rectum**, the last eight inches. The large intestine opens to the exterior of the body at the **anus**. Although most absorption occurs in the small intestine, water and some vitamins and minerals are also absorbed in the colon.

Peristalsis in the large intestine is slower than in the small intestine. Water, nutrients, and fecal matter may spend 24 hours in the large intestine, in contrast to the 3 to 5 hours it takes for chyme to move through the small intestine. This slow movement favors the growth of microorganisms. The human gut is home to about 100 trillion (10^{14}) microorganisms, 10 times the number of cells that are present in the human body itself.[1] Microorganisms are present throughout the GI tract, but the numbers and diversity are far greater in the colon than in other parts.[2] These microorganisms, consisting primarily of bacteria, are collectively referred to as the **intestinal microbiota** (previously known as the **intestinal microflora**). They produce nutrients and have other effects that impact the health of the host body, as discussed below.[2,3] Another bacterial by-product is gas, which causes flatulence. In normal adult humans, between 200 and 2000 mL of intestinal gas is produced per day.

Material that is not absorbed in the colon passes into the rectum, where it is stored temporarily and then evacuated through the anus as feces. The feces are a mixture of undigested unabsorbed matter, dead cells, secretions from the GI tract, water, and bacteria. The amount of bacteria in the feces varies but can make up more than half the weight of the feces. The amount of water in the feces is affected by fiber and fluid intake. Fiber retains water, so when adequate fiber and fluid are consumed, feces have a high water content and are easily passed. When inadequate fiber or fluid is consumed, feces are hard and dry, and difficult to eliminate.

3.4 The Gastrointestinal Tract and Health

LEARNING OBJECTIVES

- Discuss the role of the intestinal microbiota.
- Explain the role of the GI tract in immune function.
- Name three common digestive complaints, and explain their causes and consequences.
- Explain how changes in the digestive system throughout life affect digestion and absorption.

The health of the GI tract is essential to overall health. The gut not only takes nutrients into the body, but also interacts with the intestinal microbiota and serves as a barrier between the body and hazardous substances in the outside world. Some problems related to gastrointestinal function cause only minor discomfort, whereas others can be life threatening.

The Intestinal Microbiota

The right mix of microorganisms in the intestinal microbiota is important for optimal gastrointestinal function, maintenance of immune function, and for overall health.[4] An unhealthy microbiota has been implicated in the development of inflammatory intestinal diseases, such as Crohn's disease, as well as systemic chronic diseases such as obesity, diabetes, colon cancer, and atherosclerosis.[5]

Functions of the Intestinal Microbiota The intestinal microbiota interacts with both unabsorbed dietary components and the mucosal cells in the colon. The bacteria act on unabsorbed portions of food and on substances secreted by the GI tract, such as mucus, to produce nutrients that the bacteria themselves can use and that can affect the health of the host body. For example, the gut microbiota produces a number of B vitamins and vitamin K, some of which are absorbed and contribute to nutritional status in the body.[3] Bacterial breakdown of undigested carbohydrates produces small fatty acids referred to as *short-chain fatty acids*. These molecules provide energy for colonic cells and are important for regulating gut homeostasis (Figure 3.13A).[5] The presence of the microbiota and the substances it produces help maintain the mucosal layer that lines the intestine and serves as a barrier, modulate the amount of inflammation in the gut, and prevent the growth of disease-causing bacteria. The gut microbiota is also important for the maturation of the immune system, because it allows the immune system to tolerate harmless bacteria and respond to harmful ones.[5] In addition, there is evidence that the gut microbiota affects metabolism throughout the body by regulating energy intake, expenditure, and storage, as well as glucose homeostasis.[3,6]

Healthy versus Unhealthy Microbiota A healthy microbiota is diverse and resists change under physiological stress, inhibiting the growth of harmful bacteria.[5] Health is impaired when an imbalance exists between protective and harmful bacteria (Figure 3.13B). For example, an unhealthy microbiota may overstimulate the immune system, leading to excess inflammation. Patients with inflammatory bowel disease, irritable bowel syndrome, and colon cancer have been found to have increased levels of harmful bacteria and reduced levels of healthy ones.[2,5] In addition to gastrointestinal diseases, an unhealthy microbiota is believed to play a role in a number of systemic diseases. Adults with obesity, type 2 diabetes, and atherosclerosis have been found to have alterations in the composition of the gut microbiota when compared to healthy controls.[5] Although alterations in the gut microbiota are linked to these intestinal and systemic disorders, it is still not clear whether these changes contribute to the development of the disease or are a symptom of the disease.[2]

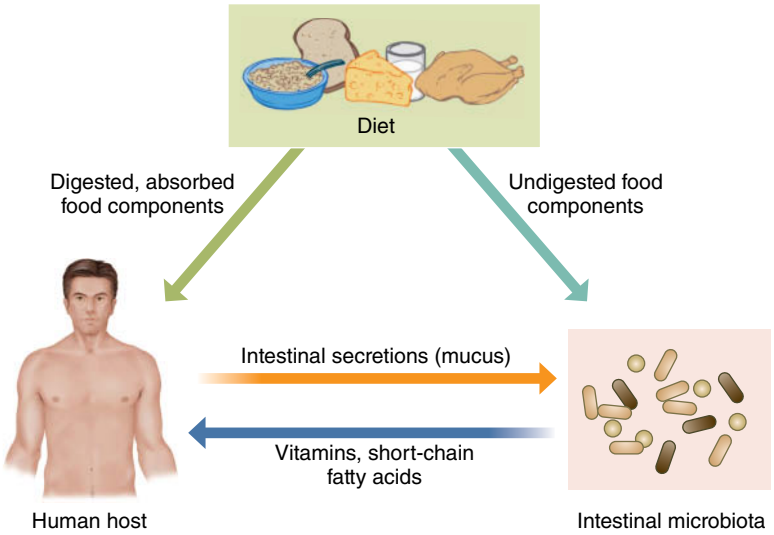
Maintaining a Healthy Microbiota The intestinal microbiota is established at birth and is affected by environmental factors, infant feeding practices, and antibiotic use.[6] Throughout life, the composition of the microbiota is affected by many factors including stress, alcohol consumption, exercise, and dietary choices.[5] Diet affects the microbiota because it determines the food available to the microorganisms in the gut and therefore what bacteria grow there (see Figure 3.13A).[2] Fibers that serve as a food supply for beneficial bacteria are called **prebiotics**. A diet high in prebiotics promotes

prebiotic A substance that passes undigested into the colon and stimulates the growth and/or activity of certain types of bacteria.

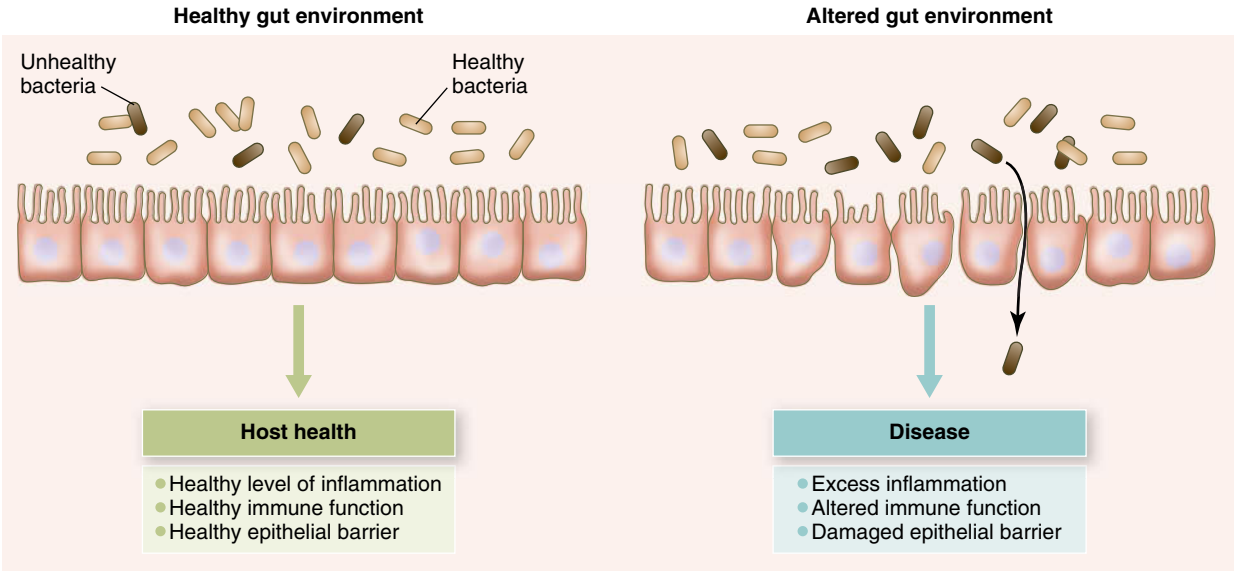
THINK CRITICALLY

Why might your doctor recommend you consume yogurt during and after a course of antibiotics?

FIGURE 3.13 Gut microbiota, nutritional status, and health



A. What we eat affects the gut microbiota, and the gut microbiota in turn enables the digestion of substances that can't be broken down by human enzymes.



B. A healthy microbiota helps prevent the growth of disease-causing organisms and moderate inflammation. Antibiotic treatment or other environmental factors that disrupt the microbial community may allow disease-causing bacteria to grow. This leads to inflammation and damage to the mucosal barrier, and possibly systemic infection.

the maintenance of a healthy microbiota. Prebiotics are found naturally in certain foods and are sold as dietary supplements.

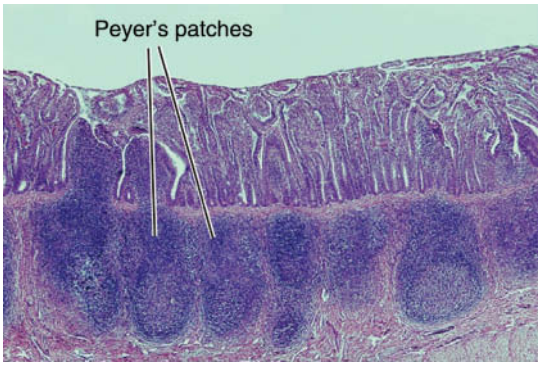
probiotic Live bacteria that, when consumed, live temporarily in the colon and confer health benefits on the host.

Another option for maintaining a healthy intestinal microbiota is the consumption of live beneficial bacteria, referred to as **probiotics**.[1] When these living bacteria, such as the *Lactobacillus* in yogurt, are consumed in adequate amounts, they live temporarily in the colon, where they inhibit the growth of harmful bacteria and confer other health benefits on the host. The bacteria must be consumed frequently because they are flushed out in the feces. Data suggest that probiotic therapy can be helpful for the prevention and treatment of antibiotic-induced diarrhea, acute infectious diarrhea, and persistent diarrhea in children.[2]

Immune Function: How Our Gut Protects Us

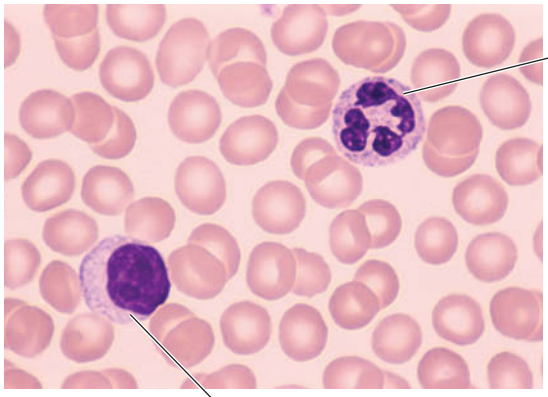
Food almost always contains bacteria and other contaminants, but it rarely makes us sick. Acid in the stomach kills most bacteria, a healthy microbiota prevents harmful bacteria from growing,

FIGURE 3.14 Immune system cells in the small intestine



Carolina Biological Supply Company/ Phototake

A. The darkly stained areas, called Peyer's patches, are made up of immune system tissue and are embedded throughout the mucosa of the small intestine. Peyer's patches contain cells that help prevent harmful organisms or materials present in the GI tract from making us ill.



Ed Reschke/Getty Images, Inc.

B. The cell in the upper right that is stained purple, is a phagocytic cell. It can engulf and destroy invading substances. The purple cell in the lower left is a lymphocyte. Lymphocytes are specific with regard to which invaders they can attack. Some lymphocytes directly kill invaders, while others secrete antibodies that help destroy antigens.

and the mucosa serves as a barrier, preventing the absorption of toxins and disease-causing organisms. The gastrointestinal tract is also an important site of immune system activity. If an invading substance, or **antigen**, enters the lumen or is absorbed into the mucosa, the immune system has a number of weapons that can destroy it before it spreads to other parts of the body. These include various types of white blood cells, which circulate in the blood and reside in the mucosa of the gastrointestinal tract (Figure 3.14A).

antigen A foreign substance (almost always a protein) that, when introduced into the body, stimulates an immune response.

When an antigen is present, phagocytes are the first types of cells to come to the body's defense (Figure 3.14B). They target any invader and engulf and destroy it. These cells also release chemicals that signal other immune system cells called *lymphocytes* to come join the fight. Lymphocytes are very specific about what they attack. Some lymphocytes bind directly to a specific invader or antigen and destroy it. This type of lymphocyte helps eliminate cancer cells, foreign cells, and cells that have been infected by viruses and bacteria. Other lymphocytes produce and secrete protein molecules called **antibodies**. Antibodies bind to invading antigens and help to destroy them. Each antibody is designed to fight off only one specific antigen. Once the body has made antibodies to a specific antigen, it remembers and can rapidly produce these antibodies to fight that antigen any time it enters the body.

antibodies Proteins produced by cells of the immune system that destroy or inactivate foreign substances in the body.

Food Allergies The immune system protects us from many invaders without our even being aware that the battle is going on. Unfortunately, the response of the immune system to a foreign substance is also responsible for allergic reactions. Food allergies occur when the body sees a food protein, called an **allergen**, as a foreign substance. The first time the protein is consumed by a susceptible individual a piece of the protein stimulates the immune system. When the protein is consumed again, the immune system recognizes it and mounts an attack, causing an allergic reaction. Allergic reactions to food can cause symptoms that range from hives to life-threatening breathing difficulties (see Chapter 6). Food allergies affect about 5% of adults and 8% of children in the United States.[7] The most common sources of food allergens are seafood, peanuts, tree nuts, fish, soy, wheat, milk, and eggs. Food labels must indicate whether a product contains any of these major food allergens (see Chapter 6, *Off the Label: Is It Safe for You?*).

allergen A substance that causes an allergic reaction.

Gluten-Related Disorders The term *gluten-related disorders* is used to describe a group of conditions that cause reactions to gluten-containing foods. They include celiac disease, non-celiac gluten sensitivity (NCGS), and wheat allergy. Celiac disease is a condition in which the protein gluten, found in wheat, barley, and rye, triggers an immune system response that damages or destroys the villi of the small intestine. For most of us, the gluten in our diet is digested and absorbed like other proteins. For people with celiac disease, also called celiac sprue, non-tropical sprue, and gluten-sensitive enteropathy, consuming even a tiny amount of gluten can cause abdominal pain, diarrhea, and fatigue. If not managed properly, the intestinal damage caused by celiac disease reduces nutrient absorption and can lead to malnutrition, weight loss, anemia, osteoporosis, intestinal cancer, and other chronic illnesses.[8] Celiac disease is an inherited condition that affects about 1% of the population.[9] It can be diagnosed by a blood test or an intestinal biopsy.

DEBATE

Should You Be Gluten Free?

You see the term "gluten free" on breakfast cereals, cake mixes, pastas, soups, and a host of other products. Celebrities are touting the benefits of going gluten free. Gwyneth Paltrow and Miley Cyrus swear by it for weight loss. Rachel Ray dedicated an entire show to gluten-free cooking. What's all the fuss?

Gluten is a protein found in wheat, barley, and rye. Gluten-free diets are essential for people who have gluten-related disorders, a spectrum of conditions including celiac disease, non-celiac gluten sensitivity (NCGS), and wheat allergy.[14] For these individuals, gluten consumption causes symptoms that are relieved by eliminating it. Completely eliminating gluten requires carefully checking each ingredient in the foods you eat to eliminate products made from, processed with, or contaminated with these grains (see table and figure). But a switch to gluten-free products has also been promoted for weight loss and to treat a host of other ailments. Is gluten free a healthy alternative for everyone?

Advocates claim that a gluten-free diet will help those suffering with gastrointestinal symptoms, joint pain, rheumatoid arthritis, osteoporosis, anemia, and diabetes. They contend that individuals with these symptoms have either undiagnosed celiac disease or NCGS. This may be the case, since only about 10 to 15% of patients with celiac disease are believed to have been diagnosed, and it is estimated that as many as 18 million Americans have NCGS.[15] For both these groups eating a gluten-free diet is likely to be of benefit. However, there is little evidence that switching to gluten free will relieve symptoms in those who do not have a gluten-related disease.[16]

What about going gluten free for weight loss or to improve overall health? Marketing has made following a gluten-free diet appear to be a healthier way of eating. However, gluten-free foods are not necessarily healthier or lower in calories than other foods. Gluten is found in breads, pastas, and breakfast cereals—all good sources of B vitamins, iron, and fiber—so if you just eliminate these foods, you will increase the risk of nutrient deficiencies. If you replace gluten-containing processed foods such as crackers, cakes, and cookies with processed gluten-free versions of these foods, you probably won't lose weight or improve the quality of your diet. If you skip high-carbohydrate, gluten-containing foods and then increase your consumption of foods high in fat and sugar, your diet could actually be less healthy and higher in calories than your original diet. But if you replace gluten-containing

Gluten-Containing Ingredients and Products

- Wheat, including wheat berries, durum, semolina, spelt, farina, faro, and graham
- Rye
- Barley
- Triticale
- Malt, including malted barley flour, malted milk or milkshakes, malt extract, malt syrup, malt flavoring, malt vinegar, malt liquor, and beer
- Brewer's yeast
- Wheat starch that has not been processed to remove gluten
- Nonfood items that may contain gluten: lipstick, lip gloss and lip balm, communion wafers, herbal or nutritional supplements, over-the-counter medications, and play dough

Non-celiac gluten sensitivity causes symptoms such as, bloating, gas, diarrhea, headache, joint and muscle pain, chronic fatigue, weight loss, and anemia. These symptoms disappear when gluten is excluded from the diet and may reappear when gluten is reintroduced.[10,11] The symptoms of NCGS are not caused by a specific immune response, and it is not known for sure whether gluten is the culprit. It is possible that wheat proteins other than gluten or small indigestible carbohydrates found in grains are responsible for the symptoms.[12,13] Wheat allergy causes symptoms after consuming wheat-containing foods. It is diagnosed by measuring blood levels of antibodies specifically to wheat.

For people with gluten-related disorders, consuming a diet that eliminates gluten provides relief from symptoms and long-term complications. This means eliminating all products made from wheat, barley, or rye, including most breads, crackers, pastas, cereals, cakes, and cookies. It also requires eliminating foods ranging from packaged gravies to soy sauce that contain trace amounts of these grains. Whether a gluten-free diet has health benefits for people without these conditions is open to debate (see **Debate: Should You Be Gluten Free?**).

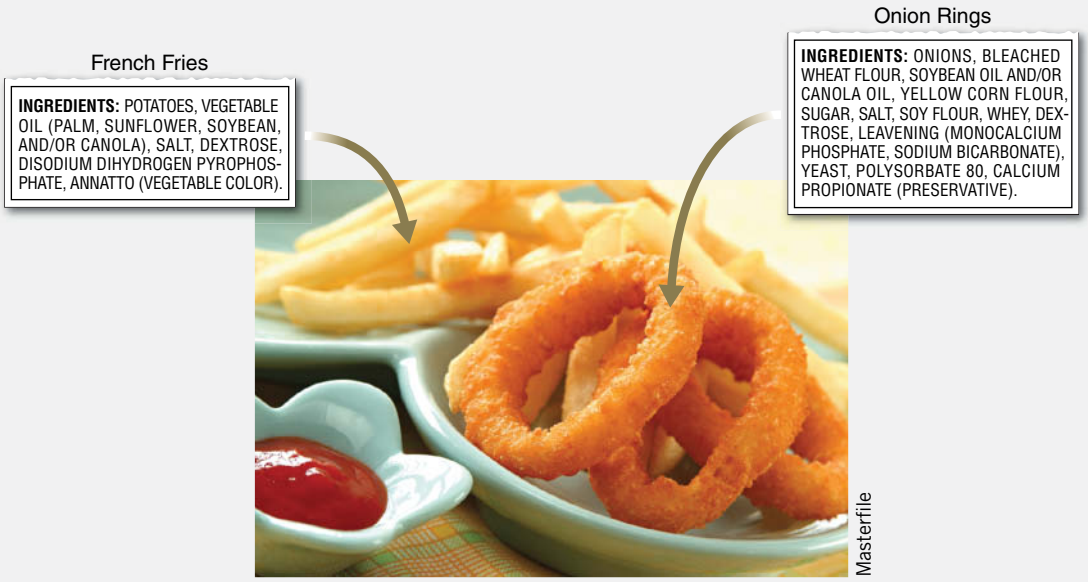
Common Digestive Complaints

Minor digestive problems, such as heartburn, constipation, and diarrhea, are common and, in most cases, have little effect on nutritional status. However, more long-term or severe problems

refined grain products with gluten-free whole grains like amaranth, millet, quinoa, and other whole foods like fresh fruits and vegetables, the switch may help you lose weight and improve your overall diet.

Is the gluten-free fad good or bad? Proponents think a gluten-free diet will improve everyone's health. And, in general, any change that makes you carefully plan your diet is a good thing. Individuals with gluten-related disorders are benefitting from the craze because it has increased the availability and quality of gluten-free foods, improved the labeling of gluten-free products, and heightened awareness of gluten-sensitive diseases. However, for those without gluten-related disorders, it unnecessarily eliminates a large number of nutrient-dense food options.

THINK CRITICALLY: Neither potatoes nor onions contain gluten. If you had celiac disease, which would be a better choice: the French fries or the onion rings?



can have serious consequences for nutrition and overall health. Some problems are so severe that nutrient needs cannot be met without alternate feeding methods.

Heartburn and GERD Heartburn is one of the most common digestive complaints. It occurs when the acidic stomach contents leak back into the esophagus, causing a burning sensation in the chest or throat (Figure 3.15). The more technical term for the leakage of stomach contents back into the esophagus is *gastroesophageal reflux*. Occasional heartburn from reflux is common, but if it occurs more than twice a week it may indicate a condition called **gastroesophageal reflux disease (GERD)**. If left untreated, GERD can eventually lead to more serious health problems such as **peptic ulcers** and cancer. Whether you have occasional heartburn or GERD, it can cause discomfort after eating a large meal and limit the types and amounts of food you can comfortably consume. Symptoms can be reduced by eating small meals and avoiding foods that trigger heartburn, such as spicy foods, fatty and fried foods, citrus fruits, chocolate, caffeinated beverages, tomato-based foods, garlic, onions, and mint. Remaining upright after eating, wearing loose clothing, avoiding smoking and alcohol, and losing weight may also help relieve symptoms. A number of medications are also available to reduce reflux symptoms. These decrease the acidity of stomach contents by either neutralizing stomach acid or blocking its production. Some of these medications can add calcium and other nutrients to the diet, but by decreasing acidity they may also reduce the absorption of nutrients that require acid to aid their

gastroesophageal reflux disease (GERD) A chronic condition in which acidic stomach contents leak back up into the esophagus, causing pain and damaging the esophagus.

peptic ulcers An open sore in the lining of the stomach, esophagus, or small intestine.

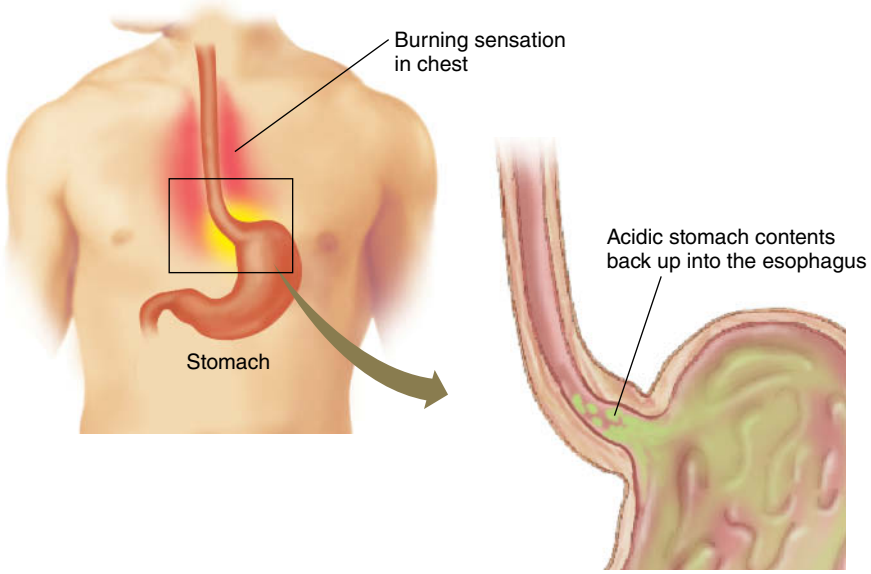


FIGURE 3.15 Heartburn and GERD
When stomach contents leak through the gastroesophageal sphincter, which separates the esophagus from the stomach, the acid irritates the lining of the esophagus.

absorption, particularly vitamin B_{12}, iron, and calcium (see **Off the Label: Antacids: Learning the Drug Facts**).

Heartburn and GERD are sometimes caused by a *hiatal hernia*. The hiatus is the opening in the diaphragm through which the esophagus passes. A hiatal hernia occurs when the upper part of the stomach bulges through this opening into the chest cavity. Hiatal hernias are common, occurring in about one-quarter of people older than age 50. They're more common in women, in smokers, and in people who are overweight. Most hiatal hernias cause no signs or symptoms, but larger ones may allow food and acid to back up into the esophagus, causing heartburn and chest pain. Hiatal hernias can usually be treated by heartburn medications, but in severe cases surgery may be needed.

Peptic Ulcers Peptic ulcers are open sores that develop in the lining of the esophagus, stomach, or upper portion of the small intestine. They occur when the mucosa is eroded away, exposing the underlying tissues to pepsin and acid in the gastric juices. If the damage reaches the nerve layer, it causes pain, and if capillaries are damaged, gastrointestinal bleeding can occur. If the ulcer perforates the wall of the GI tract, a serious abdominal infection can occur. The leading cause of ulcers is acid-resistant bacteria called *Helicobacter pylori (H. pylori)* that infect the lining of the stomach, destroying the protective mucosal layer and causing damage to the stomach wall (see **Science Applied: Discovering What Causes Ulcers**).[9,17]

Ulcers can also result from GERD or the chronic use of drugs such as aspirin and ibuprofen that erode the mucosa of the GI tract. Mild ulcers can affect nutrient intake by limiting food choices to those that do not cause discomfort, but more severe ulcers can cause bleeding that can be life threatening.

Pancreatic and Gallbladder Problems Abnormalities in the pancreas and gallbladder can affect digestion and cause discomfort. If the pancreas is not functioning normally, the availability of enzymes needed to digest carbohydrate, fat, and protein may be reduced, limiting the ability to digest and absorb these essential nutrients. If the gallbladder is not releasing bile, fat absorption can be impaired. A common condition that affects the gallbladder is gallstones. These are clumps of solid material that form in the gallbladder or bile duct and can cause pain when the gallbladder contracts in response to fat in the intestine. Gallstones can interfere with bile secretion and reduce fat absorption. They are usually treated by removing the gallbladder. Once the gallbladder has been removed, bile simply drips into the intestine as it is produced rather than being stored and squeezed out in larger amounts in response to fat in the intestine.

Diarrhea and Constipation Diarrhea and constipation are symptoms related to problems in the intestines. Diarrhea refers to frequent watery stools. It occurs when material moves through

OFF THE LABEL

Antacids: Learning the Drug Facts

© iStockphoto

Did you know that over-the-counter heartburn remedies often contain nutrients? How can you determine whether a product will affect your nutritional health in addition to relieving your heartburn? When choosing a product to treat heartburn (or any other ailment), be sure to check the label. Drug Facts labels on nonprescription drugs are designed to help consumers take medications correctly, as well as understand the drug's benefits, risks, and nutritional impact. The labels must present information in a standardized, easy-to-follow format that is as readable and as consistent as the Nutrition Facts labels on food products. The active ingredients must be listed first, along with the purpose for each, followed by uses, warnings, directions, and then inactive ingredients.[18]

The label shown here indicates that Reducid contains famotidine, a drug that reduces the amount of acid secreted by the stomach. It also contains calcium carbonate and magnesium hydroxide, antacids that contribute minerals as well as neutralize the acidity of the stomach contents. The label tells you that a single tablet contains 800 mg of calcium carbonate, which provides about 320 mg of calcium, and 165 mg of magnesium hydroxide, which provides about 69 mg of magnesium. Both nutrients are typically low in the American diet, so this product can be a welcome supplement. However, higher doses of magnesium can cause diarrhea.

Other antacids contain minerals that are not beneficial additions to the diet. For example, each tablet of Alka-Seltzer contains 567 mg of sodium, a nutrient that is excessive in the American diet. Aluminum is also found in a number of antacids; it binds phosphorus and limits its absorption and may cause constipation. The list of inactive ingredients shows that Reducid contains sugar and starch, important information for individuals who have diabetes or are consuming low-calorie diets.

If you are looking for an over-the-counter medication to treat occasional heartburn, understanding how to read the label will help you to use it correctly and to know how the product will affect your nutrient intake.

SCIENCE APPLIED

Discovering What Causes Ulcers

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

Peptic ulcers are lesions in the wall of the stomach or other part of the GI tract. They cause pain and, sometimes, bleeding. For many years they were thought to be caused by excess stomach acid. Treatments included a bland diet to avoid irritation, milk to coat the GI lining, stress reduction to decrease acid secretion, and drugs to neutralize acid or reduce its secretion. These treatments usually reduced irritation and decreased symptoms, but ulcers were a chronic condition even with treatment. Today, due to the observations and perseverance of Australian Nobel laureates B. J. Marshall and J. R. Warren, many ulcers can be cured.

THE SCIENCE

While examining stomach biopsies under a microscope, Dr. Warren observed curvy-shaped bacteria. He noticed that the bacteria were always present in tissue that was inflamed and that the number of organisms correlated with the degree of inflammation.[19] In 1982 he and Dr. Marshall isolated and grew this bacteria, later named *Helicobacter pylori (H. pylori)*, in the laboratory.[20] They believed that the bacteria were the cause of peptic ulcers.

This hypothesis, however, was not immediately embraced by the scientific community. At the time, it was assumed that ulcers were caused by too much stomach acid and it was widely accepted that bacteria could not survive in the strong acid of the stomach. To persuade other scientists that the bacteria hypothesis was correct, Marshall decided to gather data using himself as an experimental subject.

Marshall's experiment involved first having a small sample of his gastric mucosa examined to confirm that it was not infected with bacteria. He then drank a vial containing *H. pylori* that had been isolated from a patient with chronic gastric inflammation. Ten days later he developed symptoms of gastric inflammation. A follow-up sample of his gastric mucosa confirmed that his stomach lining was now inflamed and *H. pylori* bacteria could be seen attached to the mucosa (see figure).[21] Fortunately, his symptoms resolved quickly with antibiotic therapy. This confirmed the connection between *H. pylori* and stomach inflammation, but since Marshall did not develop an ulcer, that link was still unproved. The connection between *H. pylori* and ulcers was eventually supported by epidemiological studies that showed an increased incidence of ulcers in persons infected with the bacteria.[19]

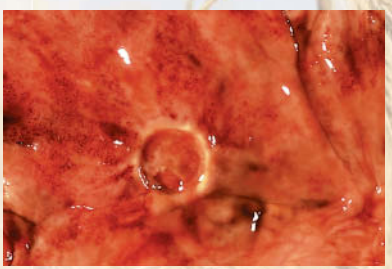
THE APPLICATION

As our understanding of how *H. pylori* survive in the acid environment of the stomach grew, the idea that bacteria caused ulcers became more universally accepted. In the stomach, *H. pylori* use a tail-like structure, called a flagella, to swim through the protective mucus layer and adhere to the mucosal cells. Once attached to the mucosal cells, they use an enzyme to produce substances that neutralize the acid immediately around them.[22] The bacteria damage mucosal cells and increase the release of gastrin, a hormone that increases stomach acid secretion.[23] The presence of this bacteria causes inflammation and other immune responses that lead to additional tissue damage. In the United States about 30 to 40% of people become infected.[24] Most do not have symptoms or go on to develop an ulcer, but having the infection puts them at risk for gastric cancer. Globally, *H. pylori* infection is believed to account for 60 to 70% of gastric cancers.[25]

Today, because of the observations and persistence of Drs. Warren and Marshall, a patient diagnosed with an ulcer and *H. pylori* infection is given antibiotics rather than a bland diet and antacids. Successful antibiotic therapy combined with acid-suppression therapy can allow the ulcer to heal, eliminate the bacteria that caused the disease, and cure the patient. A hypothesis that was at first rejected by the scientific community is now a theory supported by scientific evidence.

This electron micrograph shows the helical-shaped bacteria *Helicobacter pylori* attached to the gastric mucosa.

Science Photo Library/Photo Researchers, Inc.



CNRI/SPL/Photo Researchers, Inc.

Infection with *Helicobacter pylori* is the most common cause of ulcers, such as this one in the lining of the stomach.

the colon too quickly for sufficient water to be absorbed or when water is drawn into the lumen from cells lining the intestinal tract. Diarrhea may occur when the lining of the small intestine is inflamed so nutrients and water are not absorbed. The inflammation may be caused by infection with a microorganism or by other irritants, including foods. When harmful microorganisms infect the GI tract, diarrhea (as well as vomiting) helps to flush them out.

Constipation refers to hard, dry stools that are difficult to pass. It can occur when the diet is low in fiber or high in fiber and low in fluids, both of which cause the stool to become hard and dry and difficult to evacuate. Certain medications, lack of exercise, and a weakening of the muscles of the large intestine can also cause constipation. Constipation increases pressure in the colon and can lead to outpouches in the colon wall called *diverticula* (see Chapter 4). A condition that may cause either diarrhea or constipation is irritable bowel syndrome. Its cause is unknown, but it often results in abnormal contractions of the muscles in the intestinal wall. Symptoms include abdominal pain or cramping, bloating, gas, diarrhea, and constipation.

Some digestive problems and their causes, consequences, and solutions are summarized in Table 3.4.

TABLE 3.4 Digestive Problems and Nutritional Consequences

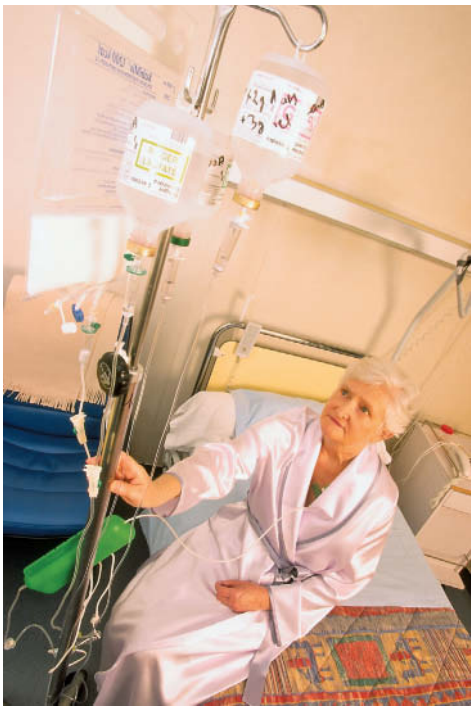
Problem	Causes	Consequences	Treatment/management
Dry mouth	Disease, medications	Decreased food intake due to changes in taste, difficulty chewing and swallowing, increased tooth decay, and gum disease	Change medications, use artificial saliva.
Dental pain and loss of teeth	Tooth decay, gum disease	Reduced food intake due to impaired ability to chew, reduced nutrient absorption due to incomplete digestion	Change consistency of foods consumed.
Heartburn, gastroesophageal reflux disease (GERD)	Stomach acid leaking into esophagus due to overeating, anxiety, stress, pregnancy, hiatal hernia, or disease processes	Pain and discomfort after eating, ulcers, increased cancer risk	Reduce meal size, avoid spicy and fatty foods, consume liquids between rather than with meals, remain upright after eating, take antacids and other medications.
Hiatal hernia	Pressure on the abdomen from persistent or severe coughing or vomiting, pregnancy, straining while defecating, excess weight, or lifting heavy objects	Heartburn, belching, GERD, and chest pain	Reduce meal size, avoid high-fat foods, consume liquids between rather than with meals, remain upright after eating, take antacids and other medications, lose weight.
Ulcers	Infection of stomach by *H. pylori*, which damages the epithelial lining; chronic use of drugs such as aspirin and ibuprofen that erode the mucosa; GERD	Pain, bleeding, and possible abdominal infection	Antibiotics to treat infection, antacids to reduce acid, change in medications.
Vomiting	Bacterial and viral infections, medications, other illnesses, eating disorders, pregnancy, food allergies	Dehydration and electrolyte imbalance; if chronic, can damage the mouth, gums, esophagus, and teeth.	Medications to treat infection, fluid and electrolyte replacement.
Diarrhea	Bacterial and viral infections, medications, food intolerance	Dehydration and electrolyte imbalance	Medications to treat infection, fluid and electrolyte replacement.
Constipation	Low fiber intake, low fluid intake, high fiber in combination with low fluid intake, weak intestinal muscles	Discomfort, intestinal blockage, formation of outpouchings in the intestinal wall called *diverticula* (see Chapter 4)	High-fiber, high-fluid diet, exercise, medications.
Irritable bowel syndrome	When the muscle contractions in the intestines are stronger and last longer than normal, or are slower and weaker than normal	Abdominal pain or cramping and changes in bowel function—including bloating, gas, diarrhea, and constipation	Manage stress and make changes in diet and lifestyle, take fiber supplements, antidiarrheal medications, other medications.
Pancreatic disease	Cystic fibrosis or pancreatitis	Malabsorption of fat, fat-soluble vitamins, and vitamin B_{12} due to reduced availability of pancreatic enzymes and bicarbonate	Oral supplements of digestive enzymes.
Gallstones	Deposits of cholesterol, bile pigments, and calcium in the gallbladder or bile duct	Pain and poor fat digestion and absorption	Low-fat diet, surgical removal of the gallbladder.

FIGURE 3.16 Alternate feeding methods

A. Enteral feeding can be delivered by a narrow tube passed through the nasal passages and into the stomach or intestine so that a liquid diet can be delivered for digestion and absorption.

Ed Eckstein/Phototake

B. If a person's GI tract is not functional, total parenteral nutrition can deliver a solution providing all of the essential nutrients directly into the bloodstream through a large vein in the upper arm or chest.



© BSIP SA/Alamy

THINK CRITICALLY

What type of carbohydrate must be used in TPN solutions? Why?

enteral or **tube-feeding** A method of feeding by providing a liquid diet directly to the stomach or intestine through a tube placed down the throat or through the wall of the GI tract.

total parenteral nutrition (TPN) A technique for nourishing an individual by providing all needed nutrients directly into the circulatory system.

How Nutrients Are Provided to People Who Can't Eat For individuals who are unable to consume food or digest and absorb the nutrients needed to meet their requirements, several alternative feeding methods have been developed. People who are unable to swallow can be fed a liquid diet through a tube inserted into the stomach or intestine. This **enteral** or **tube-feeding** can provide all the essential nutrients for patients who are unconscious or have suffered an injury to the upper GI tract (Figure 3.16A). For individuals whose GI tract is not functional, nutrients can be provided directly into the bloodstream. This is referred to as **total parenteral nutrition (TPN)** (Figure 3.16B). Carefully planned TPN can provide all the nutrients essential to life. When all nutrients are not provided in a TPN solution, nutrient deficiencies develop quickly. Inadvertently feeding patients incomplete TPN solutions has helped demonstrate the essentiality of several trace minerals.

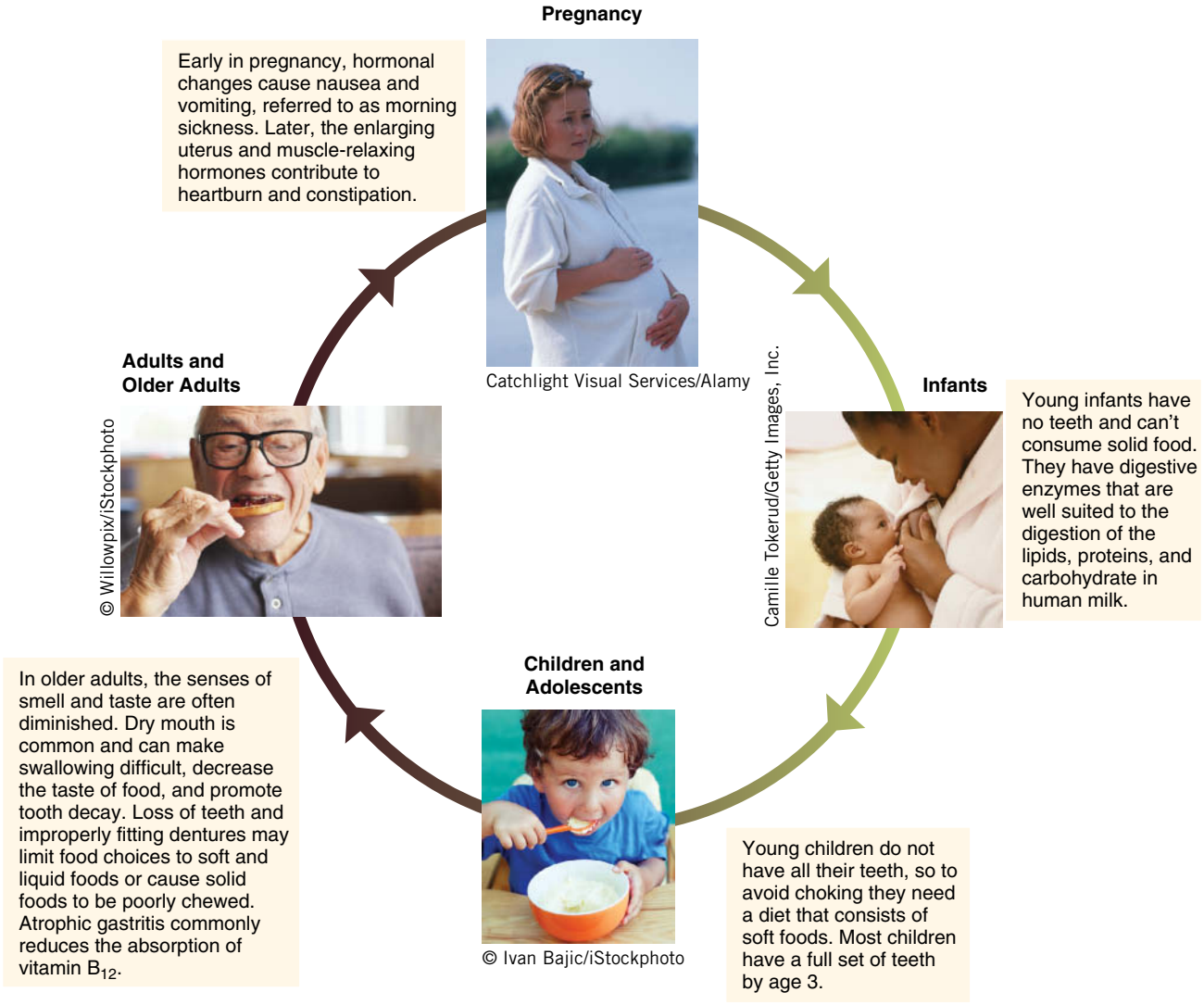
The Digestive System Throughout Life

There are some differences in the way the digestive system functions during pregnancy and infancy and with advancing age. These differences affect the ability to ingest and digest food and absorb nutrients (Figure 3.17). A well-planned diet is needed to maintain nutritional status at all stages of life.

LIFE CYCLE

Why Pregnancy Causes Digestive Discomforts Physiological changes that occur during pregnancy may cause gastrointestinal problems. During the first three months, many women experience nausea, referred to as morning sickness. This term is a misnomer, because the nausea can occur at any time of the day. Morning sickness is believed to be due to pregnancy-related hormonal changes. In most cases, it can be managed by consuming frequent small meals, eating dry crackers or cereal, and avoiding foods and smells that cause nausea. In severe cases where uncontrollable vomiting occurs, nutrients may need to be given intravenously to maintain nutritional health.

FIGURE 3.17 Gastrointestinal function throughout the life cycle



Later in pregnancy, the enlarged uterus puts pressure on the stomach and intestines, which can make it difficult to consume large meals. In addition, the placenta produces the hormone progesterone, which causes the smooth muscles of the digestive tract to relax. The muscle-relaxing effects of progesterone may relax the gastroesophageal sphincter enough to allow the stomach contents to move back into the esophagus, causing heartburn. In the large intestine, relaxed muscles and the pressure of the uterus cause less efficient peristaltic movements and may result in constipation. Increasing water intake, eating a diet high in fiber, and exercising regularly can help prevent and relieve constipation (see Chapter 14).

The Immature Infant Digestive Tract The digestive system is one of the last to fully mature in developing humans. At birth, the digestive tract is functional, but a newborn is not ready to consume an adult diet. The most obvious difference between the infant and adult digestive tracts is that newborns are not able to chew and swallow solid food. Levels of digestive enzymes in infants reflect their all-milk diet. For example, the enzyme gastric lipase plays a more important role in infants than in adults because it begins the digestion of the fats in human milk. Low levels of pancreatic enzymes in infants limit the ability to digest starch; however, enzymes at the brush border of the small intestine allow the milk sugar lactose to be digested and absorbed.

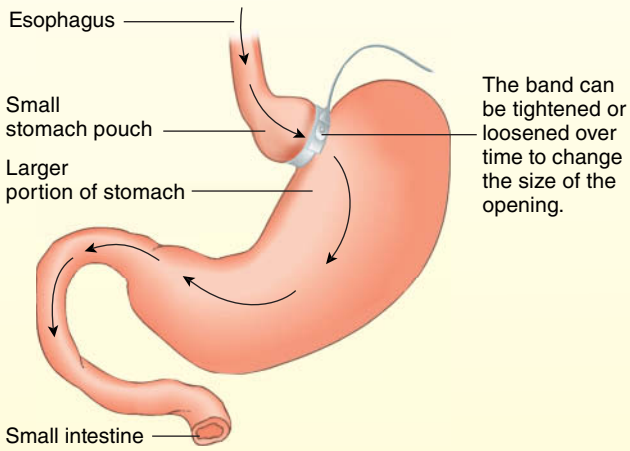
CRITICAL THINKING

How Gastrointestinal Problems Can Affect Nutrition

© Robyn Mackenzie/iStockphoto

Many factors affect how well we digest food and absorb nutrients. For each situation described below, consider how digestion and absorption are affected and what the consequences are for nutritional status.

Maria, a 40-year-old woman weighing 350 lb, has undergone a surgical procedure called gastric banding to help her lose weight. The diagram shows how her stomach was altered.



Carlos, a 50-year old man, is taking medication that reduces the amount of saliva he produces.

June, an 80-year-old woman, has dentures that don't fit well; she likes raw carrots but can't chew them thoroughly.

Asad, a 20-year-old man, has been having health problems for over a year. He was recently diagnosed with celiac disease.

After reading about the benefits of a high-fiber diet, Malik dramatically increases the amount of fiber he consumes.

iProfile Use iProfile to find out how much fiber is in a cup of raw carrots.

CRITICAL THINKING QUESTIONS

- Why can't Maria eat as much food as before the gastric banding procedure? Will the procedure affect nutrient absorption?
- What effect would reduced saliva production have on Carlos's nutrition and health?
- How will poorly fitting dentures affect how well June digests and absorbs the nutrients in the carrots?
- If Asad's celiac disease had remained undiagnosed, what long-term problems might have occurred?
- How might increasing fiber intake affect Malik's bowel movements? The amount of intestinal gas?

The ability to absorb intact proteins is greater in infants than that in adults. The absorption of whole proteins can cause food allergies (see Chapter 15), but it also allows infants to absorb immune factors from their mothers' milk. These proteins provide temporary immunity to certain diseases.

The bacteria in the large intestine of infants are also different from those in adults. At birth the infant gut has no bacteria, but the gut is quickly colonized. Because of their all-milk diet, infants' gut microbiota differs from adults' microbiota until about the second or third year of life.[2]

How the Digestive System Changes with Aging Although there are few dramatic changes in nutrient requirements with aging, changes in the digestive tract and other systems may affect the palatability of food and the ability to obtain proper nutrition. The senses of smell and taste are often diminished or even lost with age, reducing the appeal of food. A reduction in the amount of saliva may make swallowing difficult, decrease the taste of food, and also promote tooth decay. Loss of teeth and improperly fitting dentures may limit food choices to soft and liquid foods or cause solid foods to be poorly chewed. Gastrointestinal secretions may also be reduced, but this rarely impairs absorption because the levels secreted in healthy older adults are still sufficient to break down food into forms that can be absorbed. A condition called **atrophic gastritis**, which causes a reduction in the secretion of stomach acid, is also common in older adults. This may decrease the absorption of several vitamins and minerals and may allow bacterial growth to increase (see Chapters 8 and 16). Constipation is a common complaint in older adults. It may be caused by decreased motility and elasticity in the colon, weakened abdominal and pelvic muscles, and a decrease in sensory perception (see **Critical Thinking: How Gastrointestinal Problems Can Affect Nutrition**).

atrophic gastritis An inflammation of the stomach lining that causes a reduction in stomach acid and allows bacterial overgrowth.

3.5 Delivering Nutrients to Body Cells

LEARNING OBJECTIVES

- Explain why the cardiovascular system is important in nutrition.
- Discuss the role of the lymphatic system in nutrition.
- Compare the path of an amino acid to that of a large fatty acid from absorption to delivery to a cell.

Nutrients absorbed into the mucosal cells of the intestine enter the blood circulation by either the **hepatic portal circulation** or the **lymphatic system**. The hepatic portal circulation is part of the cardiovascular system, which consists of the heart and blood vessels. Amino acids from protein digestion, sugars from carbohydrate digestion, and the water-soluble products of fat digestion are absorbed into **capillaries** that are part of the hepatic portal circulation. The products of fat digestion that are not water soluble are taken into lacteals before entering the blood.

hepatic portal circulation The system of blood vessels that collects nutrient-laden blood from the digestive organs and delivers it to the liver.

lymphatic system The system of vessels, organs, and tissues that drains excess fluid from the spaces between cells, transports fat-soluble substances from the digestive tract, and contributes to immune function.

Why the Cardiovascular System Is Important in Nutrition

The cardiovascular system is a closed network of tubules through which blood is pumped. Blood carries nutrients and oxygen to the cells of all the organs and tissues of the body and removes waste products from these same cells. Blood also carries other substances, such as hormones, from one part of the body to another.

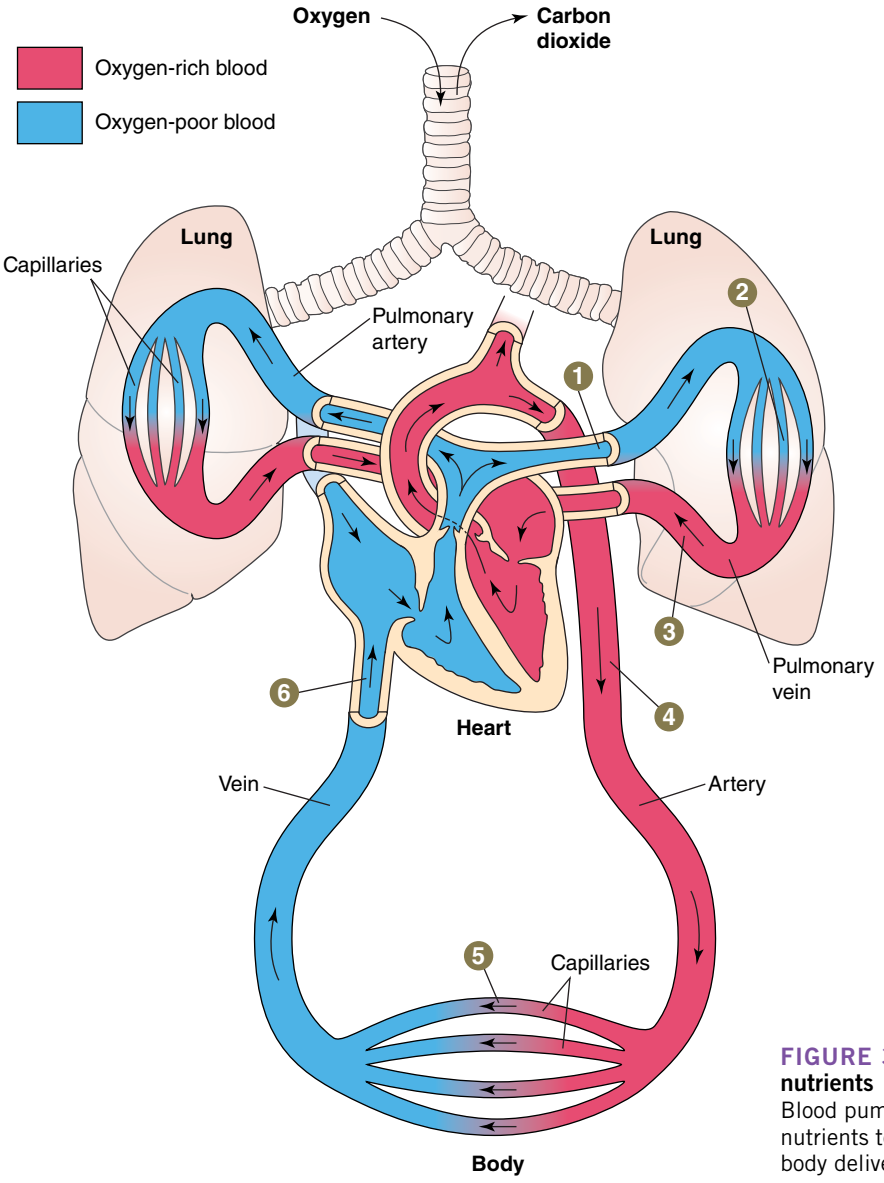
The Heart and Blood Vessels The heart is the workhorse of the cardiovascular system. It is a muscular pump with two circulatory loops—one that delivers blood to the lungs and one that delivers blood to the rest of the body (Figure 3.18). The blood vessels that transport blood and dissolved substances toward the heart are called **veins**, and those that transport blood and dissolved substances away from the heart are called **arteries**. As arteries carry blood away from the heart, they branch many times to form smaller and smaller blood vessels. The smallest arteries are called arterioles. Arterioles then branch to form capillaries. Blood flows from capillaries into the smallest veins, the venules, which converge to form larger and larger veins for return to the heart.

capillary A small, thin-walled blood vessel where the exchange of gases and nutrients between blood and body cells occurs.

vein A vessel that carries blood toward the heart.

artery A vessel that carries blood away from the heart.

The exchange of nutrients and gases occurs across the thin walls of the capillaries. In most body tissues, oxygen and nutrients carried by the blood pass from the capillaries into the cells, and carbon dioxide and other waste products pass from the cells into the capillaries. In the capillaries of the lungs, blood releases carbon dioxide to be exhaled and picks up



1. Oxygen-poor blood that reaches the heart from the rest of the body is pumped through the pulmonary arteries to the capillaries of the lungs.
2. In the capillaries of the lungs, oxygen from inhaled air is picked up by the blood, and carbon dioxide is released into the lungs and exhaled.
3. Oxygen-rich blood returns to the heart from the lungs via pulmonary veins.
4. Oxygen-rich blood is pumped out of the heart into the arteries that lead to the rest of the body.
5. In the capillaries of the body, nutrients and oxygen move from the blood to the body's tissues, and carbon dioxide and other waste products move from the tissues to the blood, to be carried away.
6. Oxygen-poor blood returns to the heart via veins.

THINK CRITICALLY

Why is the cardiovascular system important in nutrition?

FIGURE 3.18 Circulating blood delivers oxygen and nutrients
Blood pumped to the lungs picks up oxygen and delivers nutrients to the lungs. Blood pumped to the rest of the body delivers oxygen and nutrients.

oxygen to be delivered to the cells. In capillaries in the villi of the small intestine, blood delivers oxygen, removes carbon dioxide, and picks up water-soluble nutrients absorbed from the diet.

The volume of blood flow, and hence the amounts of nutrients and oxygen that are delivered to an organ or tissue, depends on the need. When you are resting, about 25% of your blood goes to the digestive system, about 20% to the skeletal muscles, and the rest to the heart, kidneys, brain, skin, and other organs.[26] This distribution changes when you eat or exercise. When you have eaten a large meal, a greater proportion of your blood goes to your digestive system to provide the oxygen and nutrients needed by the GI muscles and glands for digestion of the meal and absorption of nutrients. When you are exercising strenuously, about 70% of your blood is directed to your skeletal muscles to deliver nutrients and oxygen and remove carbon dioxide and other waste products. Attempting to exercise after a large meal creates a conflict. The body cannot supply both the intestines and the muscles with enough blood to support their respective activities. The skeletal muscles win, and food remains in the intestines, often resulting in cramps.

Most Nutrients Go Directly to the Liver In the small intestine, water-soluble molecules, including amino acids, sugars, water-soluble vitamins, and water-soluble products of fat digestion, cross the mucosal cells of the villi and enter capillaries. These capillaries merge to form venules at

the base of the villi. The venules then merge to form larger and larger veins, which eventually form the **hepatic portal vein**. The hepatic portal vein transports blood directly to the liver, where absorbed nutrients are processed before they enter the general circulation (Figure 3.19).

The liver acts as a gatekeeper between substances absorbed from the intestine and the rest of the body. Depending on the immediate needs of the body, some nutrients are stored in the liver, some are broken down or changed into different forms, and others are allowed to pass through unchanged for delivery to other body cells. For example, the liver, with the help of hormones from the pancreas, keeps the concentration of glucose in the normal range. The liver modulates blood glucose by removing absorbed glucose from the blood and storing it, by sending absorbed glucose on to the tissues of the body, or by releasing liver glucose (from stores or synthesis) into the blood. The liver also plays an important role in the synthesis and breakdown of amino acids, proteins, and fats. It modifies the products of protein breakdown to form molecules that can be safely transported to the kidneys for excretion. The liver also contains enzyme systems that protect the body from toxins that are absorbed by the GI tract.

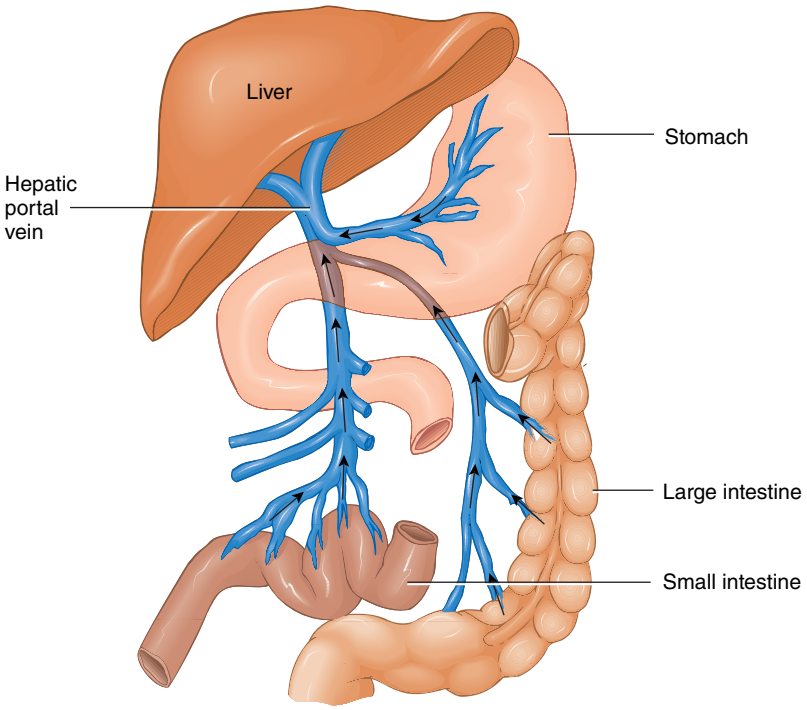


FIGURE 3.19 Hepatic portal circulation
The hepatic portal circulation carries blood from the stomach and intestines to the hepatic portal vein and then to the liver. Nutrients absorbed directly into the blood reach the liver via the hepatic portal vein.

The Roles of the Lymphatic System

The lymphatic system is important for fluid balance and immune function as well as for the absorption of lipids. It includes a network of tubules, called lymph vessels, as well as lymphatic organs and tissues that contain infection-fighting cells. Lymph vessels transport a clear fluid, called lymph. Lymph originates from the fluid that squeezes out of blood vessels and accumulates in tissues. This excess fluid drains into the lymph vessels. Unlike blood, which circulates, lymph flows only one way, draining fluid from the tissues and returning it to the blood. Before entering the bloodstream, lymph flows through lymph nodes, where infection-fighting lymphocytes and phagocytes congregate. Here foreign invaders, such as viruses and bacteria or chemicals that are harmful to the body, are removed and can trigger an immune response.

The lymphatic system is important for absorption because fat-soluble materials such as triglycerides, cholesterol, and fat-soluble vitamins are incorporated into particles that are too large to enter the intestinal capillaries (see Chapter 5). These particles pass from the intestinal mucosa into the lacteals, which drain into larger lymph vessels. Lymph vessels from the intestines and other parts of the body eventually empty into the bloodstream. Therefore, substances that are absorbed via the lymphatic system do not pass through the liver before entering the general blood circulation.

hepatic portal vein The vein that transports blood from the GI tract to the liver.

How Nutrients Enter Body Cells

In order for nutrients to be used by the body, they must enter the cells. To enter a cell, substances must first cross the **cell membrane**. The cell membrane surrounds the cell and maintains homeostasis in the cell by controlling what enters and what exits. It is **selectively permeable**, allowing some substances, such as water, to pass freely back and forth, while limiting the passage of others. Nutrients and other substances are transported from the blood into cells by simple and facilitated diffusion and active transport. Inside the cell membrane are the **cytosol**, or cell fluid, and **organelles** that perform functions necessary for cell survival. The largest organelle is the nucleus, which contains the cell's genetic material. The **mitochondrion** (plural, **mitochondria**) is the organelle where the metabolic reactions that provide energy occur. Its structure, which contains an outer and an inner membrane, facilitates its role in energy metabolism (Figure 3.20).

cell membrane The membrane that surrounds the cell contents.

selectively permeable Describes a membrane or barrier that will allow some substances to pass freely but will restrict the passage of others.

cytosol The liquid found within cells.

organelles Cellular organs that carry out specific metabolic functions.

mitochondrion (mitochondria) Cellular organelle that is responsible for providing energy in the form of ATP for cellular activities.

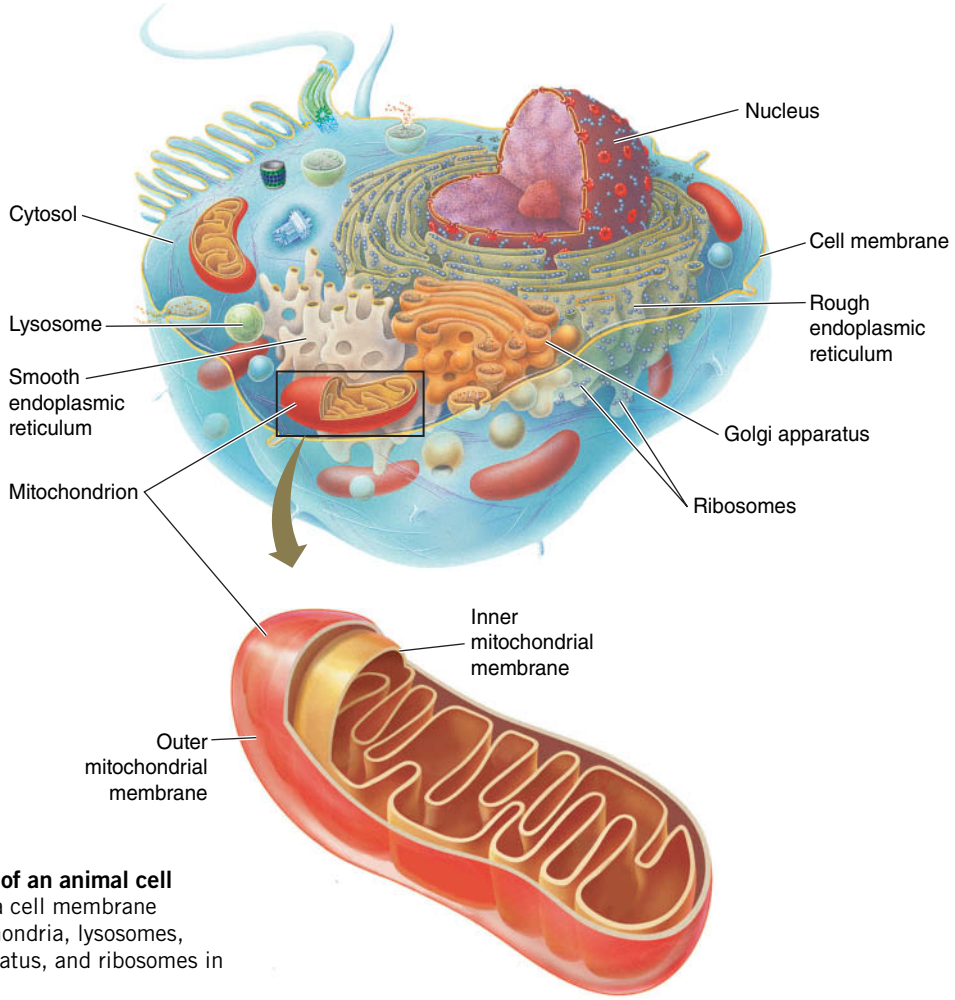


FIGURE 3.20 General structure of an animal cell
All human cells are surrounded by a cell membrane and most contain a nucleus, mitochondria, lysosomes, endoplasmic reticulum, Golgi apparatus, and ribosomes in their cytosol.

3.6 Metabolism of Nutrients: An Overview

LEARNING OBJECTIVES

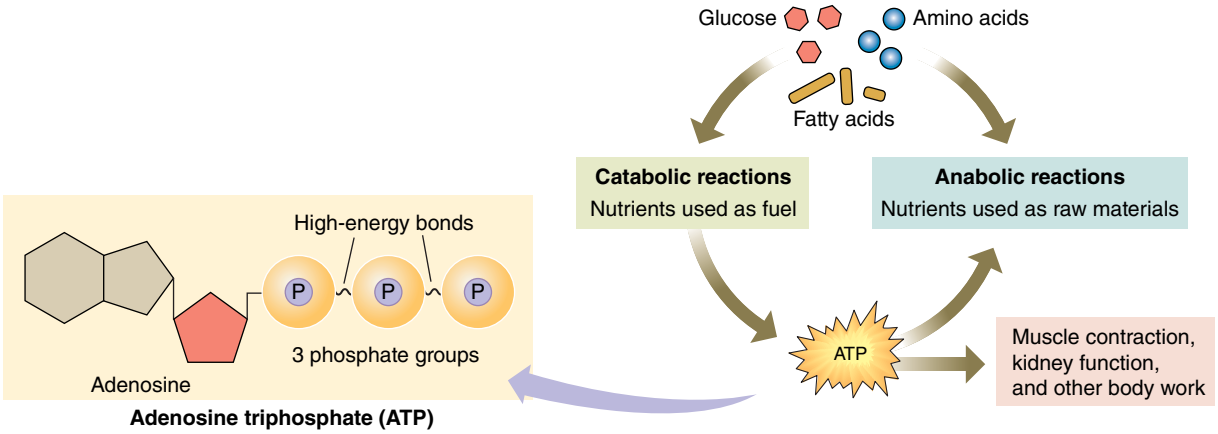
- Compare anabolic and catabolic pathways.
- Name the dietary fuel sources used to produce ATP.
- Describe the types of molecules that are synthesized from glucose, amino acids, and fatty acids.

Foods are digested and the products of digestion absorbed, transported, and delivered to body cells by the mechanisms described thus far. Once delivered to the cells, each nutrient plays a unique role in metabolism. If the proper amounts and types of nutrients are not delivered to cells, the reactions of metabolism cannot proceed optimally, resulting in poor health. The following discussion provides only a brief overview of how glucose, fatty acids, and amino acids are used by the cells to provide energy. Details about the metabolism of these energy-yielding nutrients and the role of other nutrients in metabolism will be discussed in appropriate chapters throughout this text and are reviewed in Focus on Metabolism, which can be found online.

Anabolism and Catabolism

Depending on the body's needs, the glucose, fatty acids, and amino acids absorbed from the diet are broken down to provide energy, used to synthesize essential structural or

FIGURE 3.21 ATP is the link between catabolism and anabolism



A. ATP consists of an adenosine molecule attached to three phosphate groups. The bonds between the phosphate groups are very high in energy, which is released when the bonds are broken.

B. Energy-yielding nutrients delivered to body cells can be used either in catabolic reactions to produce ATP or as raw materials in anabolic reactions that use ATP to synthesize molecules needed by the body.

regulatory molecules, or transformed into energy-storage molecules. These chemical transformations often involve a series of reactions. The series of biochemical reactions needed to go from a raw material to the final product is called a **metabolic pathway**. For each of the reactions of a metabolic pathway to proceed at an appropriate rate, an enzyme is required. These enzymes often need help from **coenzymes**. The B vitamins are important coenzymes in energy metabolism.

Some metabolic pathways break large molecules into smaller ones. These are collectively referred to as **catabolism**. Catabolic reactions release energy trapped in the chemical bonds that hold molecules together. Some of this energy is lost as heat, but some is used to synthesize a molecule called **adenosine triphosphate (ATP)** that can be used as an energy source by the body (Figure 3.21A). ATP can be thought of as the energy currency of the cell. The chemical bonds of ATP are very high in energy, and when they break, the energy is released and can be used to power body processes, such as muscle contraction or nerve conduction—or it can be used to synthesize new molecules needed to maintain and repair body tissues. Metabolic pathways that use energy from ATP to build body compounds are collectively referred to as **anabolism**. Anabolic and catabolic reactions occur in the body continually and simultaneously (Figure 3.21B).

metabolic pathway A series of chemical reactions inside a living organism that results in the transformation of one molecule into another.

coenzyme A small organic molecule (not a protein but sometimes a vitamin) that is necessary for the proper functioning of many enzymes.

catabolism The processes by which substances are broken down into simpler molecules releasing energy.

ATP (adenosine triphosphate) The high-energy molecule used by the body to perform energy-requiring activities.

anabolism The metabolic processes that use energy to combine simpler molecules to form more complex substances.

Producing ATP

Inside cells glucose, fatty acids, and amino acids derived from carbohydrates, fats, and proteins, respectively, can be broken down in the presence of oxygen to produce carbon dioxide and water. These reactions release energy that is used to produce ATP. This catabolic pathway is called **cellular respiration**. In cellular respiration, oxygen brought into the body by the respiratory system and delivered to cells by the circulatory system is used and carbon dioxide is released. This carbon dioxide is then transported to the lungs, where it is eliminated in exhaled air.

The reactions of cellular respiration are key to providing energy for all body processes. Without available oxygen, only glucose can be used to produce ATP (see Chapters 4, 13, and Focus on Metabolism). When oxygen is available, glucose, fatty acids, and amino acids can all be broken down to yield two-carbon units that form a molecule called **acetyl-CoA**. To form acetyl-CoA from glucose, it is first split in half by a pathway in the cell cytosol called *glycolysis* (see Chapter 4). To form acetyl-CoA from fatty acids, the carbon chains that make up fatty acids are broken into two-carbon units by a pathway in the mitochondria called *beta-oxidation (ß-oxidation)* (see Chapter 5). Amino acids vary in structure, but after the amino group is removed by *deamination*, they can be broken down into units that can form acetyl-CoA (see Chapter 6). Acetyl-CoA from all of these sources is broken down inside the mitochondria via the metabolic

cellular respiration The reactions that break down glucose, fatty acids, and amino acids in the presence of oxygen to produce carbon dioxide, water, and energy in the form of ATP.

acetyl-CoA A metabolic intermediate formed during the breakdown of glucose, fatty acids, and amino acids. It is a two-carbon compound attached to a molecule of CoA.

citric acid cycle Also known as the Krebs cycle or the tricarboxylic acid cycle, this is the stage of cellular respiration in which two carbons from acetyl-CoA are oxidized, producing two molecules of carbon dioxide.

electron High-energy particle carrying a negative charge that orbits the nucleus of an atom.

electron transport chain The final stage of cellular respiration in which electrons are passed down a chain of molecules to oxygen to form water and produce ATP.

oxidized Refers to a compound that has lost an electron or undergone a chemical reaction with oxygen.

reduced Refers to a substance that has gained an electron.

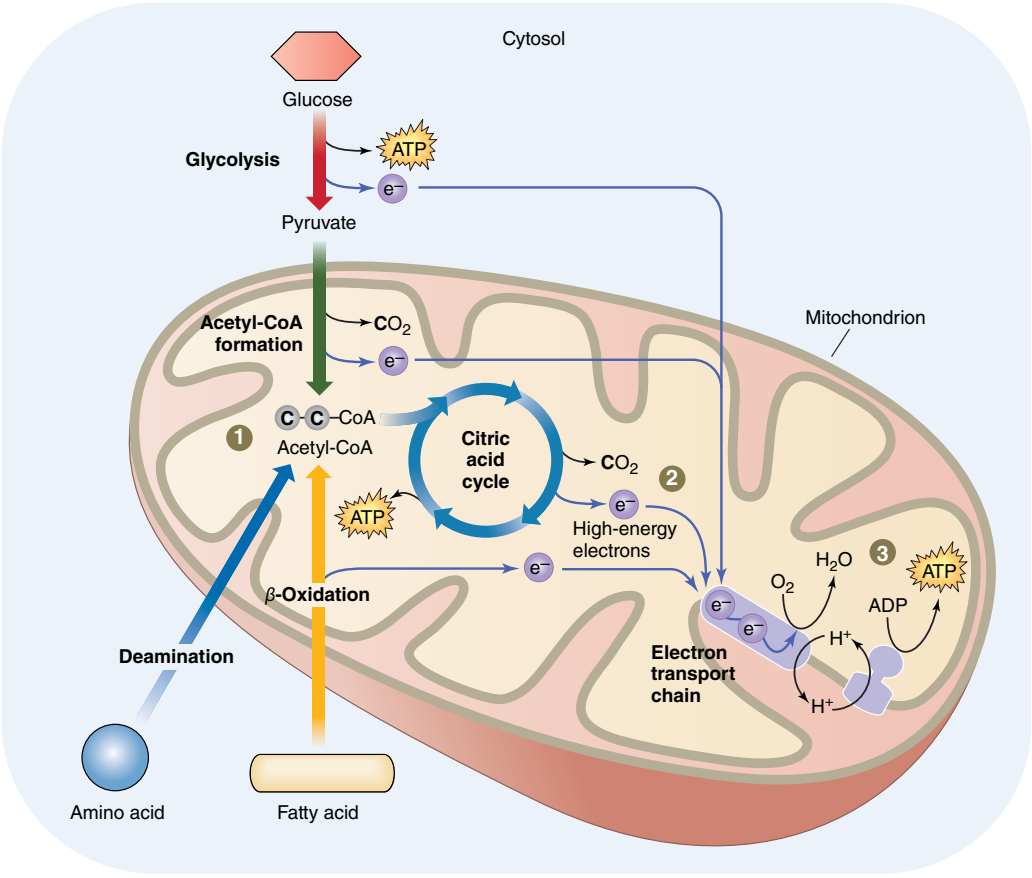
pathway known as the **citric acid cycle**. In this pathway, the two carbons of acetyl-CoA are removed one at a time, forming carbon dioxide molecules, releasing **electrons**, and generating a small amount of ATP. The electrons, which are high in energy, are passed to shuttling molecules for transport to the **electron transport chain** (Figure 3.22).

The electron transport chain consists of a series of molecules that accept electrons from the shuttling molecules and pass them from one to another down the chain. When one substance loses an electron, another must pick up that electron. A substance that loses an electron is said to be **oxidized** and one that gains an electron is said to be **reduced**. Reactions that transfer electrons are called *oxidation-reduction reactions* and are very important in energy metabolism. As electrons are passed along the electron transport chain, their energy is released and used to add a phosphate group to adenosine diphosphate (ADP) to form ATP. The final molecule to accept electrons in the electron transport chain is oxygen. When oxygen accepts electrons it is reduced and combines with hydrogen to form a molecule of water (see Figure 3.22).

Synthesizing New Molecules

Glucose, fatty acids, and amino acids that are not broken down for energy are used in anabolic pathways to synthesize structural, regulatory, or storage molecules. Glucose molecules can be used to synthesize glycogen, a storage form of carbohydrate. If the body has enough glycogen, glucose can also be used to synthesize fatty acids. Fatty acids can be used to synthesize

FIGURE 3.22 Cellular respiration
Cellular respiration uses oxygen to convert glucose, fatty acids, and amino acids into carbon dioxide, water, and energy, in the form of ATP.



1. In the presence of oxygen, glucose, fatty acids, and amino acids can be metabolized to produce acetyl-CoA.
2. Acetyl-CoA is broken down by the citric acid cycle to yield carbon dioxide (CO_2) and high-energy electrons.
3. The electrons are shuttled to the electron transport chain where their energy is used to convert ADP to ATP. They eventually combine with oxygen and hydrogen to form water.

triglycerides that are stored as body fat. Amino acids can be used to synthesize the various proteins that the body needs, such as muscle proteins, enzymes, protein hormones, and blood proteins. Amino acids can also be used to synthesize glucose. Excess amino acids can be converted into fatty acids and stored as body fat.

3.7 Elimination of Metabolic Wastes

LEARNING OBJECTIVES

- Distinguish the substances that are eliminated in the feces from those lost in the urine.
- List four routes for eliminating waste products from the body.

Substances that cannot be absorbed into the body, such as fiber, are excreted from the GI tract in feces. Metabolic wastes, such as carbon dioxide, nitrogen, and water, which are generated by nutrient metabolism, must also be removed from the body. These are eliminated by the lungs, the skin, and the kidneys. Figure 3.23 illustrates the routes by which wastes are eliminated from the body.

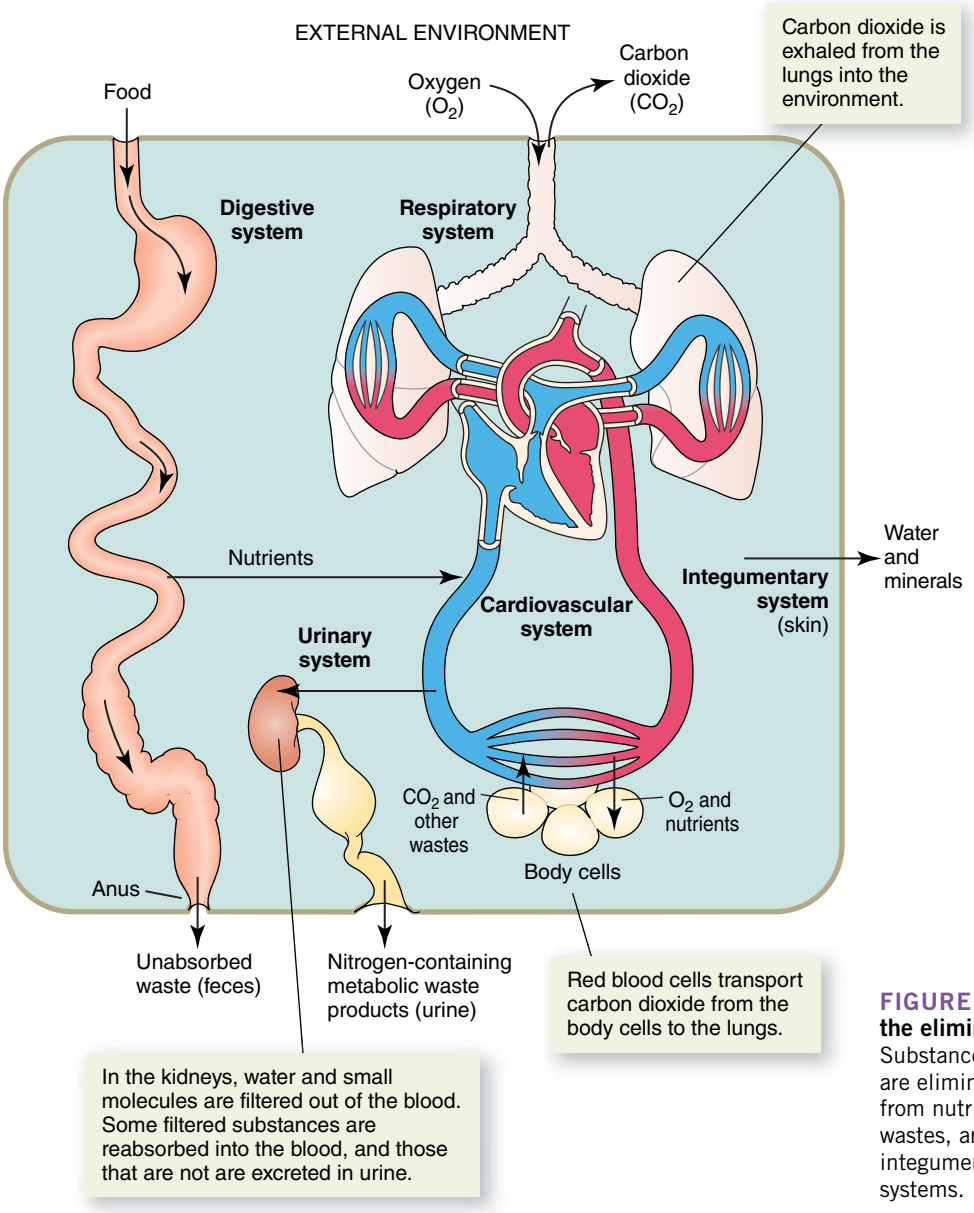


FIGURE 3.23 Organ systems involved in the elimination of wastes
Substances in food that cannot be absorbed are eliminated in the feces. Wastes generated from nutrient metabolism, called metabolic wastes, are eliminated from the body by the integumentary (skin), urinary, and respiratory systems.

The Respiratory System and Skin

Carbon dioxide produced by cellular respiration leaves the cells and is transported to the lungs by red blood cells. At the lungs, red blood cells release their load of carbon dioxide, which is then exhaled. In addition to carbon dioxide, a significant amount of water is lost from the lungs by evaporation. Water, along with protein-breakdown products and minerals, is also lost through the skin in perspiration or sweat.

The Kidneys

nephron The functional unit of the kidney that performs the job of filtering the blood and maintaining fluid balance.

glomerulus A ball of capillaries in the nephron that filters blood during urine formation.

The kidneys, which are part of the urinary system, are the primary means for the excretion of water, metabolic waste products, and excess minerals. Each kidney consists of about 1 million **nephrons**. The nephrons consist of a **glomerulus**, where the blood is filtered, and a series of tubules, where molecules that have been filtered out of the blood can be reabsorbed. As blood flows through the glomerulus, most of the small dissolved molecules are filtered out. Protein molecules and blood cells are too large to be removed by the glomerulus. Filtered substances that are needed are then reabsorbed back into the blood. Components that are not needed are not reabsorbed and are passed down the ureters to the bladder and excreted in the urine. The amounts of water and other substances excreted in the urine are regulated so that homeostasis is maintained (see Chapter 10).

OUTCOME

After talking with her doctor, Gillian learned that the way she was eating was contributing to her GERD symptoms. Her meals were free at the restaurant, but eating spicy, high-fat foods while running around at work was making her symptoms worse. She now knows that eating while bending, lifting, and rushing around can delay stomach emptying and force the acidic contents back up out of her stomach. Her choice of foods and eating just before going to bed also exacerbated her symptoms. To manage her GERD, Gillian began eating better throughout the day. She now gets up earlier to make time for breakfast, and packs a sandwich so she can have a healthy lunch. At work, she sits down for fifteen minutes before her shift to eat a quick but relaxed meal. She is careful not to eat acidic foods like orange juice and tomato sauce, spicy foods like peppers, and high fat-foods like cheese and pepperoni, which slow stomach emptying. By not going to bed with a full stomach and elevating the head of her bed, Gillian is able to prevent reflux while sleeping. After a few weeks, she is off her medication and her symptoms have all but disappeared. Gillian has had to change her lifestyle to manage this condition. **If she reverts to her previous habits, symptoms will likely return.**

SUMMARY

3.1 Food Becomes Us

- Our bodies and the foods we eat are all made from the same building blocks—atoms. Atoms are linked by chemical bonds to form molecules.
- Molecules can be organized to form cells, which are the smallest unit of life. Cells of similar structure and function are organized into tissues and tissues into organs. Organs cooperate to form the organ systems that make up the entire organism.

3.2 The Digestive System

- The digestive system is the organ system primarily responsible for the movement of nutrients into the body. The digestive system provides two major functions: digestion and absorption. Digestion is the process by which food is broken down into units that are small enough to be absorbed. Absorption is the process by which nutrients are transported into the body.
- The digestive system consists of the gastrointestinal tract and accessory organs. The GI tract consists of a hollow tube that begins at the mouth and continues through the pharynx, esophagus, stomach, small intestine, and large intestine.
- The digestion of food and the absorption of nutrients in the lumen of the GI tract are aided by the secretion of mucus and enzymes.
- The passage of food and the secretion of digestive substances are regulated by nervous and hormonal signals.

3.3 Digestion and Absorption

- The processes involved in digestion begin in response to the smell or sight of food and continue as food enters the digestive tract at the mouth.
- In the mouth, food is broken into smaller pieces by the teeth and mixed with saliva. The chemical digestion of carbohydrate is begun in the mouth by the enzyme salivary amylase.
- From the mouth, food passes through the pharynx and into the esophagus. The rhythmic contractions of peristalsis propel it down the esophagus to the stomach.
- The stomach acts as a temporary storage tank for food. The muscles of the stomach mix the food into a semiliquid mass called chyme, and gastric juice containing hydrochloric acid and pepsin begins protein digestion. Stomach emptying is regulated by the amount and composition of food consumed and by nervous and hormonal signals from the stomach and small intestine.
- The small intestine is the primary site of nutrient digestion and absorption. The small intestine contains large circular folds, villi, and microvilli, all of which increase the absorptive surface area. Chyme is propelled through the small intestine by peristalsis, and mixed by the contractions of segmentation. In the small intestine, bicarbonate from the pancreas neutralizes stomach acid, and pancreatic and intestinal enzymes digest carbohydrate, fat, and protein. The digestion of fat in the small intestine is aided by bile from the gallbladder. Bile helps make fat available to fat-digesting enzymes by breaking it into small droplets and also facilitates fat absorption.
- The absorption of food across the intestinal mucosa occurs by several different processes. Simple diffusion, osmosis, and facilitated diffusion do not require energy but can only move substances from an area of higher concentration to an area of lower concentration. Active transport requires energy but can transport substances against a concentration gradient.
- Components of chyme that are not absorbed in the small intestine pass on to the large intestine, where some water and nutrients are absorbed. The large intestine is populated by microorganisms known as the intestinal microbiota. They digest some unabsorbed material and affect our overall health. The remaining unabsorbed materials are excreted in feces.

3.4 The Gastrointestinal Tract and Health

- The intestinal microbiota produces some vitamins and short-chain fatty acids that fuel colonic cells. A healthy microbiota supports digestive and immune health and is believed to protect against intestinal disorders as well as systemic diseases like diabetes.
- Immune system cells and tissues located in the gastrointestinal tract help eliminate disease-causing organisms and toxins. Abnormalities in immune function are the cause of food allergies and celiac disease.
- Heartburn and GERD are common digestive problems that are caused by the leakage of acidic stomach contents into the esophagus. Peptic ulcers are caused by infection with *Helicobacter pylori*, GERD, or medications that damage the mucosa. Gallstones can cause pain and interfere with fat digestion and absorption. Diarrhea may occur when the lining of the small intestine is inflamed so nutrients and water are not absorbed. Constipation can be caused by a diet that is low in fiber or high in fiber and low in fluids.
- Tube-feeding can nourish patients who are unable to swallow food on their own. Total parenteral nutrition is necessary when the gut is not able to digest and or absorb nutrients.
- Digestive system function is affected by life stage. During pregnancy, physiological changes cause morning sickness, heartburn, and constipation. During infancy, the immaturity of the GI tract limits what foods can be ingested and digested. In older adults, changes in the digestive tract may decrease the appeal of food and the ability to digest and absorb nutrients.

3.5 Delivering Nutrients to Body Cells

- Absorbed nutrients are delivered to the cells of the body by the cardiovascular system. The heart pumps blood to the lungs to pick up oxygen and eliminate carbon dioxide. From the lungs, blood returns to the heart and is pumped to the rest of the body to deliver oxygen and nutrients and remove carbon dioxide and other wastes before returning to the heart. Blood is pumped away from the heart in arteries and returned to the heart in veins. Exchange of nutrients and gases occurs at the smallest blood vessels, the capillaries.
- The products of carbohydrate and protein digestion and the water-soluble products of fat digestion enter capillaries in the intestinal villi and are transported to the liver via the hepatic portal circulation. The liver serves as a processing center, removing the absorbed substances for storage, converting them into other forms, or allowing them to pass unaltered. The liver also protects the body from toxic substances that may have been absorbed.
- The lymphatic system is important for fluid balance, immune function, and the absorption of the fat-soluble products of digestion. Lipid transport particles are absorbed into lacteals in the intestinal villi. Lacteals join larger lymph vessels. The nutrients absorbed via the lymphatic system enter the blood circulation without first passing through the liver.
- Cells are the final destination of absorbed nutrients. To enter the cells, nutrients must be transported across the cell membrane.

3.6 Metabolism of Nutrients: An Overview

- Within the cells, glucose, fatty acids, and amino acids absorbed from the diet can be broken down to provide energy in the form of ATP, used to power body activities and synthesize essential structural or regulatory molecules, or be transformed into energy storage molecules. The sum of all the chemical reactions of the body is called metabolism.
- The catabolic reactions that completely break down macronutrients in the presence of oxygen to produce water, carbon dioxide, and ATP are referred to as cellular respiration. Glucose, fatty acids, and amino acids can all be broken down into two-carbon molecules that form acetyl-CoA. The reactions of the citric acid cycle and the electron transport chain complete the breakdown of acetyl-CoA to form carbon dioxide and water and generate ATP.
- Anabolic reactions use glucose, fatty acids, and amino acids to synthesize structural, regulatory, or storage molecules.

3.7 Elimination of Metabolic Wastes

- Unabsorbed materials are excreted in the feces. Carbon dioxide is eliminated in exhaled air. Water is lost via the lungs and skin.
- Water, metabolic waste products, and excess minerals are excreted by the kidneys.

CHAPTER OUTLINE

4.1 Carbohydrates in Our Food
How Refined and Unrefined Carbohydrates Differ
Why We Should Limit Added Sugars

4.2 Types of Carbohydrates
Simple Carbohydrates
Complex Carbohydrates

4.3 Carbohydrates in the Digestive Tract
Carbohydrate Digestion and Absorption
Lactose Intolerance
Fiber in the Digestive Tract

4.4 Carbohydrates in the Body
Carbohydrate Functions
Delivering Glucose to Body Cells
How Glucose Provides Energy
What Happens When Carbohydrate Is Limited?

4.5 Carbohydrates and Health
Diabetes Mellitus
Hypoglycemia
Dental Caries
Carbohydrates and Weight Management
Carbohydrates and Heart Disease
Fiber and Bowel Health
Fiber and Colon Cancer

4.6 Meeting Recommendations for Carbohydrate Intake
Carbohydrate Recommendations
Translating Recommendations into Healthy Diets
The Role of Alternative Sweeteners

(©iStockphoto)

Shaiith/iStock/Getty Images

Carbohydrates: Sugars, Starches, and Fiber

4

CASE STUDY

Shamara was excited when she lost 15 pounds in only a few weeks on a low-carbohydrate diet. She had cut out all the chips, cookies, and soda that she usually snacked on while studying or picked up while rushing between classes. She had also cut out the bagel she ate for breakfast, her sandwich at lunch, and the French fries that she enjoyed with dinner. But, after a month, she was so tired of the diet that she fell back into her old eating habits. She quickly regained half of the weight she had lost. Now Shamara has decided to forget the low-carb diet and just focus on eating healthy foods. She looked up her MyPlate recommendations and was surprised to find that not all carbohydrates are bad—MyPlate recommended that she eat six servings of grain products, at least three of which should be whole grains. She also saw that she needed to increase her intake of fruits and vegetables. Most fruits and vegetables had been forbidden on her low-carb diet because they contain carbohydrate, but MyPlate recommended fruits and vegetables fill half her plate because they are good sources of vitamins, minerals, and fiber.

The first step Shamara took was to replace the bags of chips that she kept in her dorm room with oranges and apples. With those healthy snacks available, she would be less tempted to hit the vending machine for a midnight snack. She went back to eating a bagel or cereal for breakfast and made sure she chose whole-grain varieties. When she had her diet analyzed at a health fair a few weeks later, she was shocked to see that even after all the changes she had made, her diet was still high in added sugars. She decided to be more mindful and started by looking at the food labels of what she'd eaten that day. She found that the bran muffin she had after her first class had 15 grams of sugar, and though her breakfast cereal box had a big banner saying it had 5 g of fiber, the food label showed that it also contained 18 g of sugar, about half the amount in a can of soda. **Choosing healthy carbohydrates was turning out to be almost as difficult as eliminating them.**

© Elena Elisseeva/Alamy

4.1 Carbohydrates in Our Food

LEARNING OBJECTIVES

- Identify the sources of refined and unrefined carbohydrates in the typical American diet.
- Discuss why the recommendations for a healthy diet promote unrefined carbohydrates.
- Explain why added sugars should be limited in the diet.

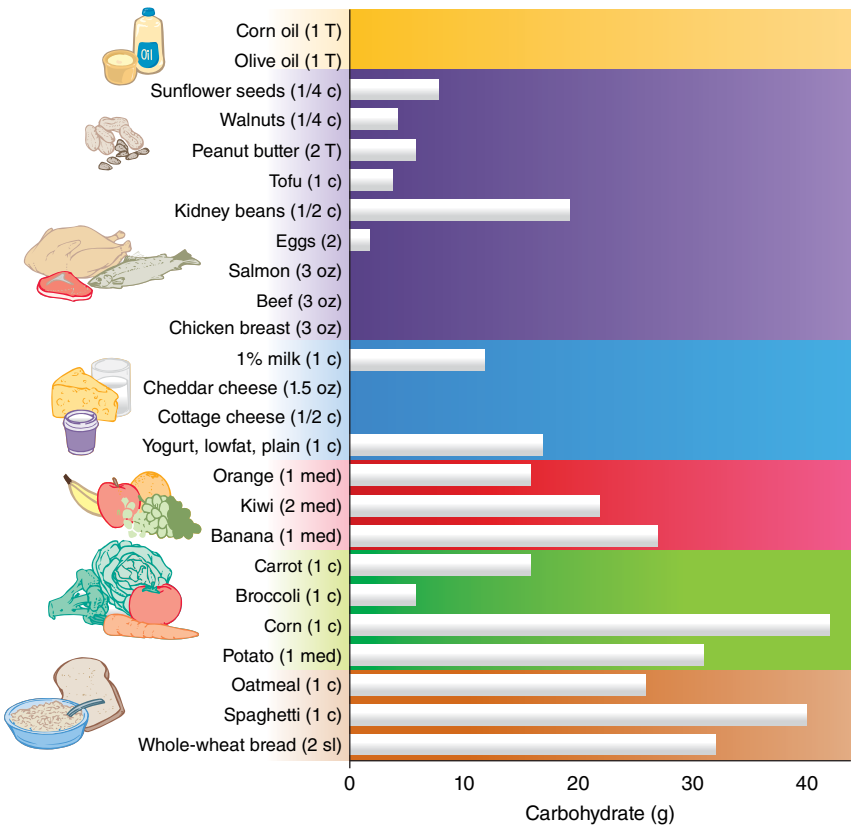
Foods that are high in carbohydrates are the basis of our diet; carbohydrates provide more than half of calories in the American diet. Foods as diverse as oatmeal, whole-wheat bread, fresh fruit, milk, chocolate cake, potato chips, and carbonated soft drinks are high in carbohydrates (Figure 4.1A). The carbohydrates in these foods provide a readily available source of energy; they supply 4 kilocalories per gram (kcal/g). However, the additional nutritional impact they deliver varies depending on whether or not the carbohydrate has been **refined**.

refined Refers to foods that have undergone processing that removes various components of the original food.

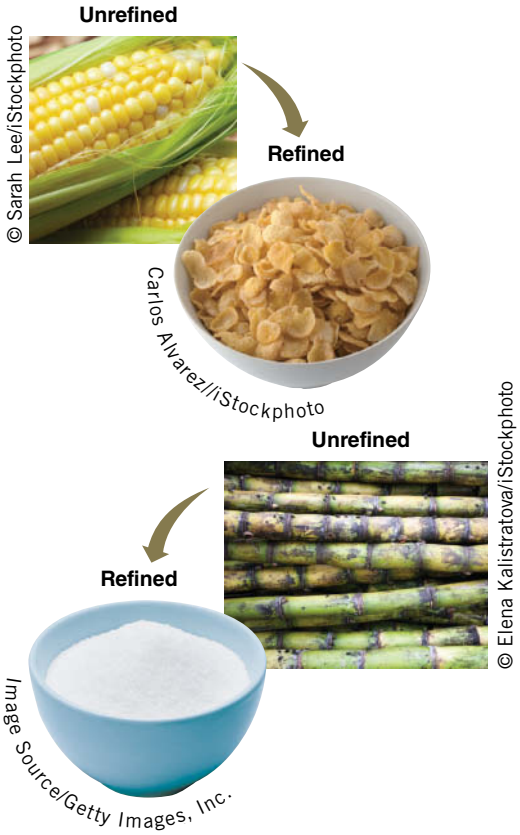
Oatmeal, brown rice, fresh fruit, and milk are considered unrefined or whole food sources of carbohydrates. These foods contain vitamins, minerals, and other health-promoting substances as well as carbohydrates. Potato chips, cakes, cookies, and carbonated soft drinks provide carbohydrates that have been refined. Refining separates carbohydrates from many of the other essential nutrients and food components present in the whole food.

During the past century the amounts and sources of carbohydrates in the American diet have changed. Our total carbohydrate intake decreased between 1909 and 1963. Most of this drop was due to a decrease in the consumption of whole grains, and with it came a 40% drop in the amount

FIGURE 4.1 Carbohydrate comes from whole and refined sources



A. Grains, vegetables, legumes, fruits, nuts, seeds, and milk are all whole sources of carbohydrates.



B. Corn is an unrefined source of carbohydrate, but the corn in cornflakes has been processed by grinding, cooking, extruding, and drying. Although many cereals today are made from whole grains, these cornflakes are a refined product that is missing some of the fiber and other nutrients present in whole corn. The sugar you sprinkle on cornflakes is also a refined carbohydrate; it has been processed from sugarcane or sugar beets.

of fiber consumed.[1] Since the 1960s, our total carbohydrate intake has increased, but our fiber intake did not rise with it, suggesting an increase in the intake of refined carbohydrates. Much of the carbohydrate added back to our diet between 1960 and 2000 came from sugars; over this time period per-capita sugar consumption rose by 33%.[2] Whole-grain breads and cereals were replaced by white bread, snack foods, and sugared soft drinks. The types of sweeteners also changed. In the 1960s we sweetened food with cane and beet sugar, but by 2000, most of the foods we bought were sweetened with corn sweeteners (see **Debate: Should You Avoid High-Fructose Corn Syrup?**).

Today, our diets remain high in refined grains and sugars. Recommendations for a healthy diet tell us to choose more of the unrefined carbohydrates we used to eat, whole grains, vegetables, **legumes**, and fruits, and fewer foods high in refined carbohydrates and **added sugars** such as baked goods and sugar-sweetened beverages.

How Refined and Unrefined Carbohydrates Differ

Unrefined sources of carbohydrate such as whole grains, legumes, vegetables, fruits, and milk contain a variety of nutrients in addition to carbohydrates. Whole grains, legumes, and vegetables provide B vitamins, some minerals, fiber, and phytochemicals. Fruits provide vitamins A and C along with fiber. Milk is a good source of the B vitamin riboflavin and the mineral calcium. In contrast, refined sources of carbohydrate, such as the cornflakes you may have had for breakfast, are made from corn that has been refined and processed into crunchy flakes; many of the nutrients and other healthful components of the corn kernel are lost (Figure 4.1B). When we eat the entire kernel or seed of a grain, such as corn, rice, or wheat, we are eating an unrefined or **whole-grain** product. The whole-grain kernel includes the bran, the germ, and the endosperm (Figure 4.2A).

The outermost **bran** layers of a kernel of grain contain most of the fiber and are a good source of vitamins. The **germ**, which lies at the base of the kernel, is the plant embryo where sprouting occurs. It is the source of some vegetable oils, such as corn oil, and is rich in vitamin E. It also contains protein, fiber, and the B vitamins riboflavin, thiamin, and vitamin B_6. The remainder of the kernel is the **endosperm**, which is primarily starch but also contains most of the protein and some vitamins and minerals. During the milling of grain into flour, the grinding detaches the germ and bran from the endosperm. Whole-grain flours such as whole-wheat flour include most of the bran, germ, and endosperm. White flour, however, is produced from just the endosperm. Fiber and some vitamins, minerals, and phytochemicals naturally found in the whole grain are therefore lost. To restore some of the lost nutrients, refined grains sold in the United States are **enriched** with some, but not all, of the nutrients lost in processing. Enriched grains contain added thiamin, riboflavin, niacin, and iron and are fortified with folate. However, they do not contain added vitamin E, magnesium, vitamin B_6, or a number of other nutrients, whose levels are also reduced by milling (Figure 4.2B).

legumes Plants in the pea or bean family that produce an elongated pod containing large starchy seeds. Green peas, kidney beans, and peanuts are legumes.

added sugars Sugars and syrups that have been added to foods during processing or preparation.

whole grain The entire kernel of grain including the bran layers, the germ, and the endosperm.

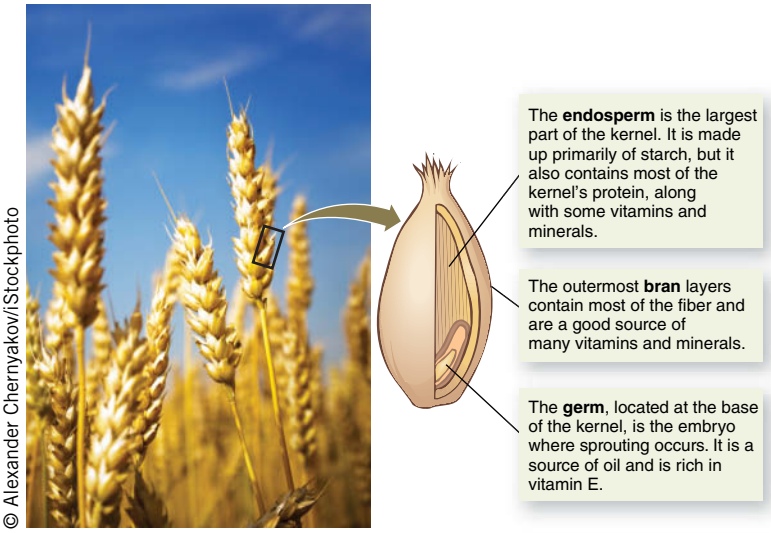
bran The protective outer layers of whole grains. It is a concentrated source of dietary fiber.

germ The embryo or sprouting portion of a kernel of grain. It contains oil, protein, fiber, and vitamins.

endosperm The largest portion of a kernel of grain. It is primarily starch and serves as a food supply for the sprouting seed.

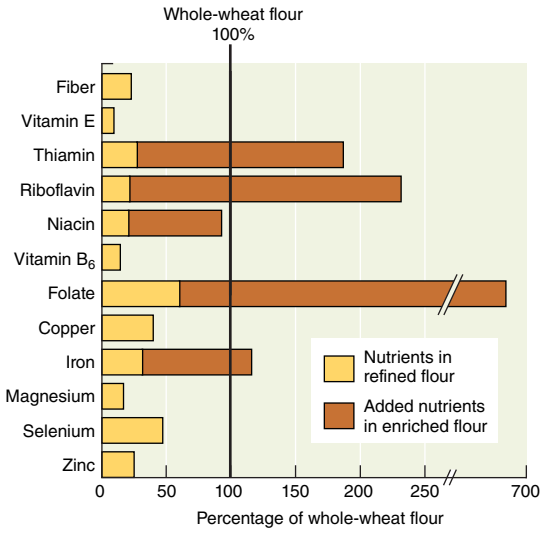
enriched Refers to a food that has had nutrients added to restore those lost in processing to a level equal to or higher than originally present.

FIGURE 4.2 Whole grains and nutrient composition



© Alexander Chernyakov/iStockphoto

A. A kernel of grain, such as the wheat shown here, is made up of three major components: the bran, the germ, and the endosperm.



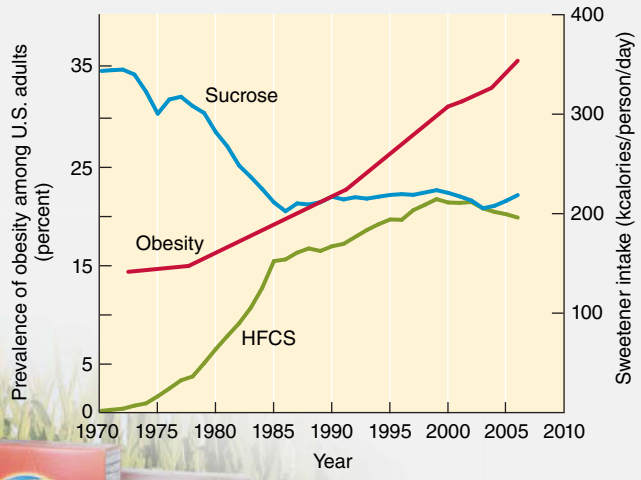
B. The amounts of many nutrients in refined flour (yellow bars) are much lower than the amounts originally present in the whole grain (100% line). In enriched flour, thiamin, riboflavin, niacin, iron, and folate have been added back in amounts that equal or exceed the original levels (brown bars).

DEBATE

Should You Avoid High-Fructose Corn Syrup?

High-fructose corn syrup (HFCS) is the most common added sweetener in the American diet. It was developed in the 1960s as a convenient and inexpensive way to sweeten food. Between 1970 and 1990, HFCS consumption increased more than 1000%.[3] The ubiquitous use of this sweetener has created concern about the effect it has on our health. Increased

Since 1970, HFCS intake has increased dramatically, while sucrose use has declined. Over this same time period, the incidence of obesity has more than doubled.



Andy Washnik photo and composition. Background corn photo from Bill Grove/istockphoto.com

A large range of processed refined foods, from carbonated beverages and fruit drinks to cereals, crackers, barbecue sauce, and salad dressings, contain high-fructose corn syrup.

Why We Should Limit Added Sugars

The sugar you sprinkle on your cereal adds calories without adding any nutrients other than carbohydrate. This reduces the nutrient density of your breakfast. But the sugar you add to your food at the table isn't the only source of added sugars in the diet—much of the added sugar we consume comes from desserts, beverages, and snacks that we purchase already prepared. Refined added sugars make up about 13% of the calories in the American diet.[14] Refined sugars added to foods are not nutritionally or chemically different from sugars occurring naturally in foods. The only difference

consumption of HFCS has been related to the development of obesity, heart disease, and diabetes, among other disorders.[4] Is HFCS just a convenient way to sweeten our food, or is it a threat to our health?

HFCS is a syrup made by extracting starch from corn and treating it to break the bonds between the glucose molecules. The resulting corn syrup is then treated to convert about half the glucose to fructose (hence "high-fructose" corn syrup). Manufacturers prefer HFCS as an added sweetener because it is cheaper and more stable during storage than other sweeteners. In 1970, the most common sweetener in the American diet was sucrose (see graph). Today HFCS has almost completely replaced sucrose in soft drinks and is found in many other foods, ranging from breakfast cereals to canned soups and salad dressings.

HFCS has been implicated as a cause of obesity because obesity rates began to rise at the same time HFCS use increased (see graph). There is some physiological basis for the relationship between fructose and obesity. When excess energy is consumed, fructose is converted to fat more readily than glucose. A study in humans found a greater amount of abdominal fat in subjects consuming diets high in fructose compared with glucose.[5] In addition, fructose is not as effective as glucose at stimulating the release of hormones that suppress appetite or at inhibiting the release of hormones that stimulate appetite.[6] So, when compared to glucose, fructose consumption contributes more to fat synthesis and less to appetite suppression, potentially leading to overeating and weight gain.

A number of counterarguments have been made regarding the contention that HFCS contributes to obesity more than other sweeteners.[7] First, obesity has increased dramatically in countries that do not use HFCS, and in the United States obesity rates continued to increase even after HFCS consumption leveled off.[8] The most compelling argument as to why HFCS is not to blame for obesity is that it is really no different than sucrose.[7] Sucrose is 50% fructose, whereas the HFCS used in soft drinks is about 55% fructose. In the gastrointestinal tract sucrose is digested to glucose and fructose, so free fructose and glucose are absorbed whether you consume HFCS or sucrose. There is no metabolic reason why the fructose in HFCS is more damaging than the fructose in sucrose.

We gain excess body weight by consuming more calories than we expend. Calories from beverages, whether sweetened with sucrose or HFCS, are a particular concern because consuming liquids does not make you feel as full as eating the same calories from solid food, and when people get calories from liquids they don't compensate for these calories by eating less food.[9,10] Many studies have shown a positive association between sweetened beverage consumption and the risk of obesity in adults.[10,11] An animal study suggests that this is due to the HFCS. In the study rats fed a diet supplemented with water sweetened with HFCS gained more weight and more fat than did rats supplemented with sucrose-sweetened water, despite actually consuming fewer calories.[12] However, studies in humans have found responses to consumption of HFCS and sucrose to be the same with regard to its biologic actions and effect on food intake.[8] In a study of weight-loss diets containing 20% of calories from HFCS or sucrose, similar weight changes were seen.[13]

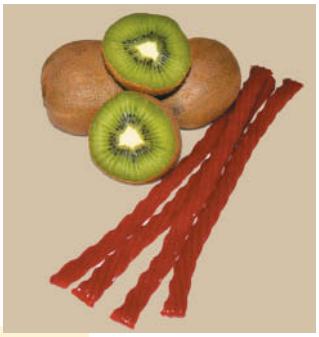
When consumed in large amounts, HFCS has the potential to both increase energy intake and promote the deposition of body fat. But is HFCS worse than other sweeteners? Will eliminating HFCS from our food supply necessarily make our diets healthier?

THINK CRITICALLY: Will replacing HFCS with sucrose help reduce obesity?

is that they have been separated from their plant sources and therefore are not consumed with all of the fiber, vitamins, minerals, and other substances found in the original plant. Because refined sugars provide few nutrients for the number of calories they contain, they have a low nutrient density and are considered empty calories. Unrefined or whole food sources of sugar such as fruit provide vitamins, minerals, and phytochemicals as well as calories. For example, three kiwis provide the same number of calories as four pieces of red licorice, but the kiwis are more nutrient dense because they provide a variety of other nutrients, in addition to sugar (Figure 4.3).

THINK CRITICALLY

If you choose the licorice, what food or foods could you add to provide the same amount of vitamin C and folate you would have gotten from the kiwis?



M. Price/John Wiley & Sons

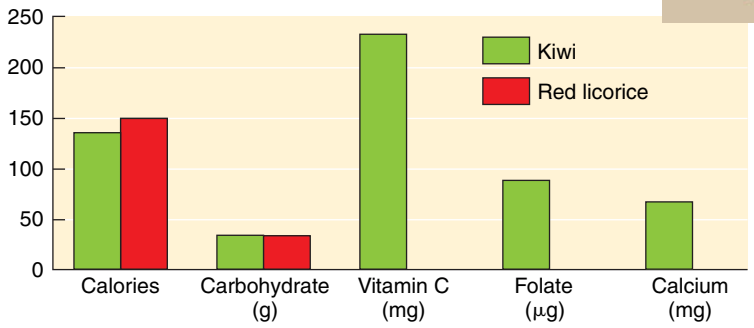


FIGURE 4.3 Added versus naturally occurring sugar
Kiwis are a more nutrient-dense snack than red licorice. Although three kiwis provide about the same number of calories as four pieces of licorice, the kiwis are an unrefined source of sugar that also provides fiber, vitamin C, folate, and calcium. Most of the calories in the licorice are from added refined sugars; it contains few other nutrients.

4.2 Types of Carbohydrates

LEARNING OBJECTIVES

- Compare the structures of simple and complex carbohydrates.
- List food sources of simple carbohydrates and complex carbohydrates.
- Distinguish between soluble and insoluble fiber, and name food sources of each.

monosaccharide A carbohydrate made up of a single sugar unit.

disaccharide A carbohydrate made up of two sugar units.

polysaccharide A carbohydrate made up of many sugar units.

simple carbohydrates A class of carbohydrates, known as sugars, that includes monosaccharides and disaccharides.

glucose A monosaccharide that is the primary form of carbohydrate used to provide energy in the body. It is the sugar referred to as blood sugar.

fructose A monosaccharide that is the primary form of carbohydrate found in fruit.

Chemically, carbohydrates are compounds made up of one or more sugar units that contain carbon (*carbo-*), as well as hydrogen and oxygen in the same two-to-one proportion found in water (*-hydrate*, H_2O). Carbohydrates made up of only one sugar unit are called **monosaccharides** (*mono-* means one), those made up of two sugar units are called **disaccharides** (*di-* means two), and those made up of more than two sugar units are called **polysaccharides** (*poly-* means many).

Simple Carbohydrates

Monosaccharides and disaccharides are classified as **simple carbohydrates** or sugars. Fruits, vegetables, and milk are whole food sources of simple carbohydrates. The sugars we add to food such as white table sugar, brown sugar, molasses, and confectioner's sugar, as well as the high-fructose corn syrup added in processing, are also simple carbohydrates. These are produced by refining and processing the carbohydrates from plants such as sugarcane, sugar beets, and corn.

Monosaccharides The monosaccharide **glucose**, commonly referred to as blood sugar, is the most important carbohydrate fuel for the body. Glucose is produced in plants by the process of photosynthesis, which uses energy from the sun to combine carbon dioxide and water (Figure 4.4). Glucose rarely occurs as a monosaccharide in food. It is most often found as part of a disaccharide or starch.

Two other common monosaccharides in the diet are fructose and galactose. Like glucose, each contains 6 carbon, 12 hydrogen, and 6 oxygen atoms, but they differ in their arrangement (Figure 4.5A). **Fructose** is a monosaccharide that tastes sweeter than glucose. It is found in fruits and vegetables and makes up more than half the sugar in honey. Because fructose does not cause as great a rise in blood glucose as other sugars, it is sometimes used in products for people with diabetes. However, because fructose causes an increase in blood lipids, its use should be limited. Fructose consumed in fruits or juices can also cause diarrhea in children. Most of the fructose

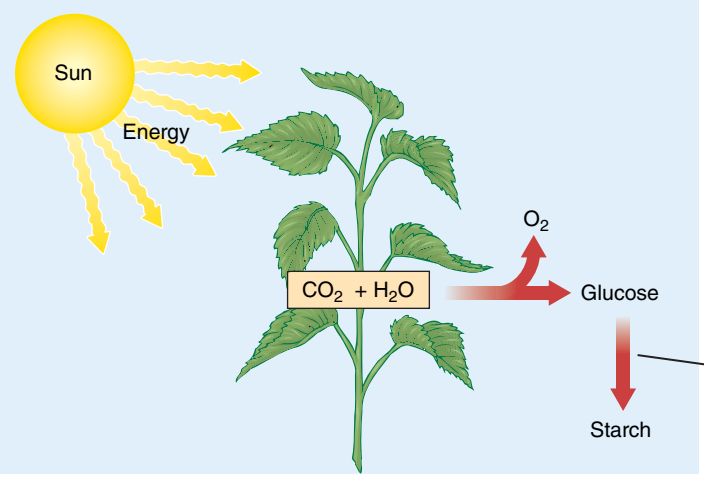


FIGURE 4.4 Photosynthesis
Glucose is produced in plants through the process of photosynthesis, which uses energy from the sun to convert carbon dioxide and water to glucose.

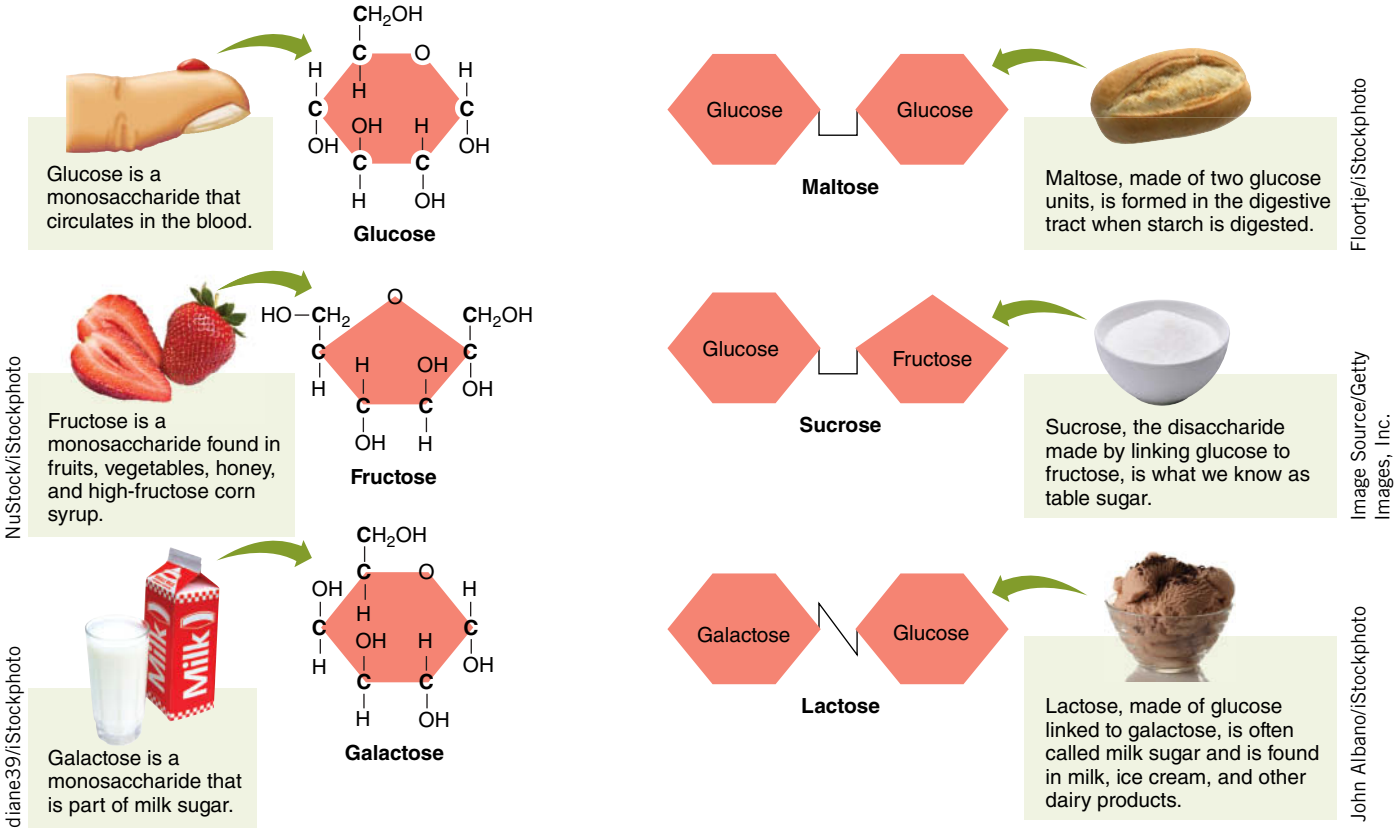
in our diet comes from high-fructose corn syrup, which is used in most soft drinks in the United States (see *Debate: Should You Avoid High-Fructose Corn Syrup?*). **Galactose** is rarely present as a monosaccharide in the food supply but is a part of lactose, the disaccharide in milk.

galactose A monosaccharide that combines with glucose to form lactose, or milk sugar.

Disaccharides The most common disaccharides in our diet are maltose, sucrose, and lactose (Figure 4.5B). **Maltose** consists of two molecules of glucose. This sugar is made whenever starch is broken down. For example, it is responsible for the slightly sweet taste experienced when bread is held in the mouth for a few minutes. As salivary amylase begins digesting the starch,

maltose A disaccharide made up of two molecules of glucose. It is formed in the intestines during starch digestion.

FIGURE 4.5 Simple carbohydrates include monosaccharides and disaccharides



A. Glucose, fructose, and galactose are monosaccharides that have the same chemical formula, but their atoms are arranged differently.

B. Maltose, sucrose, and lactose are disaccharides made up of different pairs of monosaccharides.

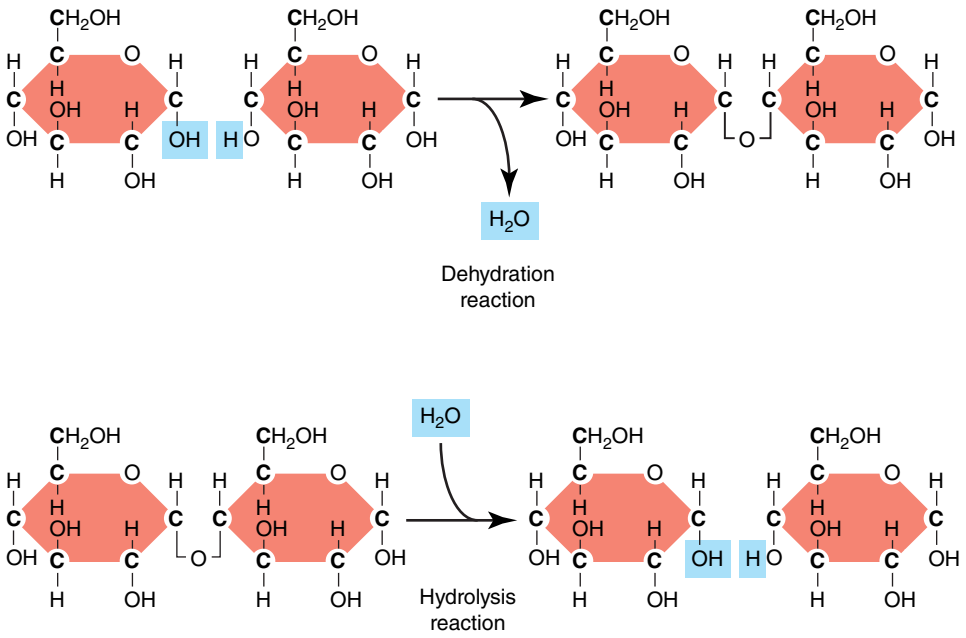


FIGURE 4.6
Dehydration and hydrolysis reactions
In the dehydration reaction (top), two glucose molecules are joined to form the disaccharide maltose and a molecule of water. In the hydrolysis reaction (bottom), the addition of a molecule of water breaks maltose into its component glucose molecules.

sucrose A disaccharide that is formed by linking fructose and glucose. It is commonly known as table sugar or white sugar.

lactose A disaccharide that is formed by linking galactose and glucose. It is commonly known as milk sugar.

some sweeter-tasting maltose is formed. **Sucrose**, or common white table sugar, is the disaccharide formed by linking glucose to fructose. It is found in sugarcane, sugar beets, honey, and maple syrup. Sucrose is the only sweetener that can be called "sugar" in the ingredient list on food labels in the United States. **Lactose**, or milk sugar, is glucose linked to galactose. Lactose is the only sugar found naturally in animal foods. It contributes about 30% of the energy in whole cow's milk and about 40% of the energy in human milk.

Making and Breaking Sugar Chains

The type of reaction that links two sugars together is called a dehydration reaction (Figure 4.6). Dehydration reactions are a type of condensation reaction that combines two molecules by releasing a molecule of water, in this case by taking a hydroxyl group (OH) from one sugar and a hydrogen atom (H) from the other. The type of chemical reaction that breaks the bonds between sugar molecules is called a hydrolysis reaction. Hydrolysis reactions cleave chemical bonds by adding water; in this case a hydroxyl group is added to one sugar and a hydrogen atom to the other.

Complex Carbohydrates

complex carbohydrates Carbohydrates composed of sugar molecules linked together in straight or branching chains. They include oligosaccharides, glycogen, starches, and fibers.

oligosaccharides Short-chain carbohydrates containing 3 to 10 sugar units.

glycogen A carbohydrate made of many glucose molecules linked together in a highly branched structure. It is the storage form of carbohydrate in animals.

Complex carbohydrates are generally not sweet to the taste like simple carbohydrates. They include short chains of 3 to 10 monosaccharides called **oligosaccharides** and longer-chain polysaccharides. The longer polysaccharides include glycogen in animals and starch and fiber in plants.

Oligosaccharides

Some oligosaccharides are formed in the gastrointestinal tract during the breakdown of larger polysaccharides. These are then further digested to simple sugars. Other oligosaccharides are found naturally in foods such as beans and other legumes, onions, bananas, garlic, and artichokes. Many of these are not digested by human enzymes in the digestive tract and pass into the colon where they are broken down by the intestinal microbiota. These indigestible oligosaccharides are a type of fiber. They can affect the mix of microorganisms in the microbiota, and therefore gastrointestinal (GI) and overall health (see Chapter 3). Oligosaccharides present in human milk make the infant stool easier to pass, help promote the growth of a healthy intestinal microbiota, and may protect the infant from infections that cause diarrhea.[15]

Glycogen

Glycogen is the storage form of carbohydrate in animals. It is a polysaccharide made up of highly branched chains of glucose molecules (Figure 4.7). The branched structure allows it to be broken down quickly when glucose is needed. In humans, glycogen is stored in the muscles and in the liver. Muscle glycogen provides glucose to the muscle as a source of energy during activity; liver glycogen releases glucose into the bloodstream for delivery to cells throughout the

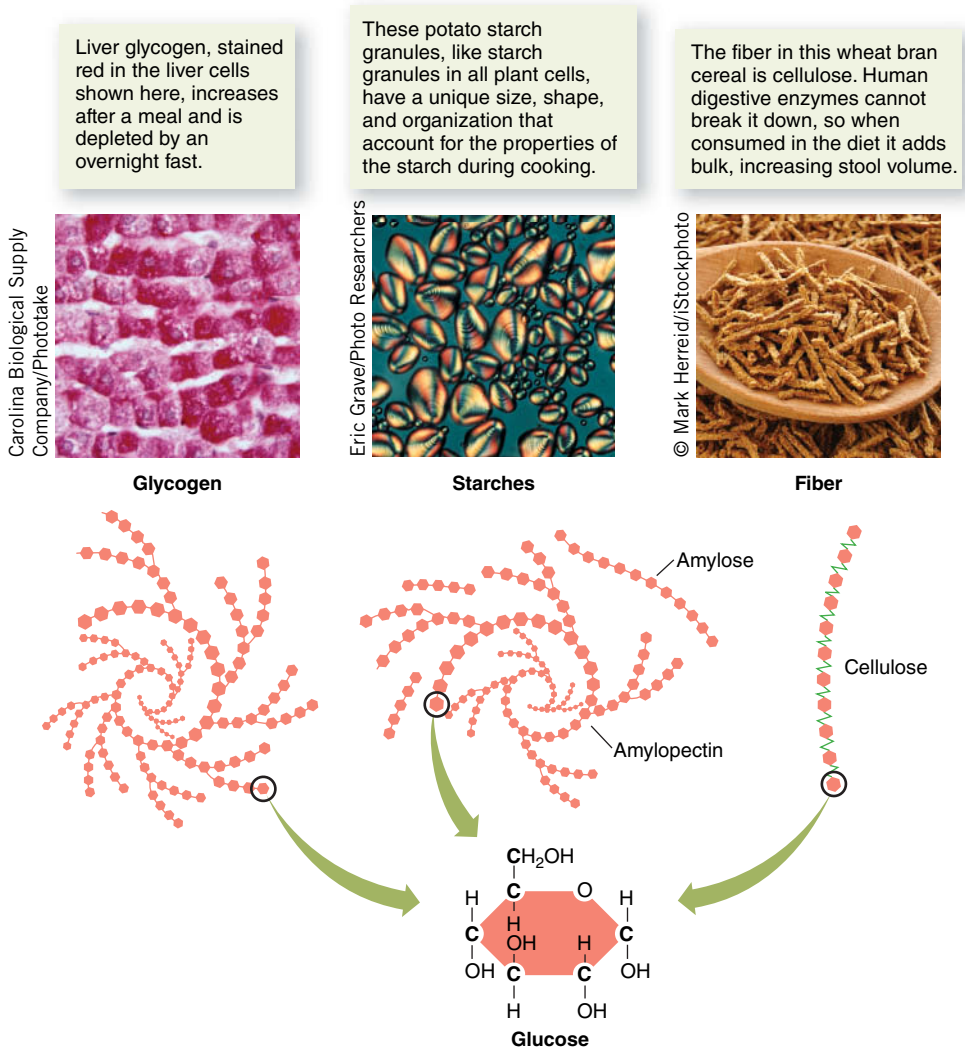


FIGURE 4.7 Complex carbohydrates
Glycogen, starches, and the fiber cellulose are complex carbohydrates made up of straight or branching chains of glucose.

body. We don't consume glycogen in our food because glycogen present in animal muscles is broken down soon after slaughter and thus is not present when the meat is consumed.

The amount of glycogen that can be stored in the body is relatively small—about 200 to 500 g. The amount of glycogen stored in muscle can be temporarily increased by a regimen called *carbohydrate loading* or *glycogen supercompensation*. This regimen is often used by endurance athletes to build up glycogen stores before an event. Extra glycogen can mean the difference between running only 20 miles or finishing a 26-mile marathon before exhaustion takes over. Glycogen supercompensation is discussed in more detail in Chapter 13.

Starches

Starch is the storage form of carbohydrate in plants. Starch is made up of two types of molecules: amylose, which consists of long straight chains of glucose molecules, and amylopectin, which consists of branched chains of glucose molecules (see Figure 4.7). Starch accumulates in roots and tubers (the underground energy-storage organ of some plants), such as potatoes, sweet potatoes, beets, turnips, and cassava, where it provides energy for the growth and reproduction of the plant. Starch also accumulates in seeds as an energy source for the developing plant embryo. We consume starch in the seeds of grains, such as wheat, barley, and rye, and of legumes, such as lentils, soybeans, and pinto and kidney beans. In addition to the starch naturally present in foods, the diet also contains refined starch such as cornstarch, which is added to thicken foods such as sauces, puddings, and gravies. Starch can be used to thicken foods because starch granules absorb water and swell when they are heated in water (see Figure 4.7). As a starch-thickened mixture cools, bonds form between molecules in high-amylose starches, forming a gel. Some starches are treated to enhance their ability to form a gel. These modified food starches are added to processed foods as thickeners.

starch A carbohydrate made of many glucose molecules linked in straight or branching chains. The bonds that hold the glucose molecules together can be broken by human digestive enzymes.

FIGURE 4.8 Sources of fiber
Whole grains, legumes, fruits, and vegetables are good sources of soluble and/or insoluble fiber.

Good sources of soluble fiber:
Legumes
Prunes
Apricots
Raisins
Oranges
Bananas
Oats
Apples
Eggplant
Flaxseed

Charles D. Winters

Good sources of insoluble fiber:
Wheat bran
Whole-wheat bread
Broccoli
Corn
Eggplant
Apple skins
Nuts and seeds

fiber A mixture of indigestible carbohydrates and lignin that is found in plants.

soluble fiber Fiber that dissolves in water or absorbs water to form viscous solutions and is readily broken down by the intestinal microbiota. It includes pectins, gums, and some hemicelluloses.

insoluble fiber Fiber that, for the most part, does not dissolve in water and is less readily broken down by the microbiota of the large intestine. It includes cellulose, some hemicelluloses, and lignin.

resistant starch Starch that is classified as fiber because it escapes digestion in the small intestine of healthy people.

Fiber **Fiber** includes carbohydrates and lignins (substances in plants that are not carbohydrates but are classified as fiber) that cannot be digested by human enzymes (see Figure 4.7). Because fiber cannot be digested, it cannot be absorbed, so it passes into the colon. Fiber can have beneficial health effects, from reducing constipation to lowering blood cholesterol and modulating rises in blood glucose.

Traditionally, fiber has been classified as **soluble fiber** or **insoluble fiber** based on solubility in water. In general, soluble fibers form viscous solutions when mixed with water and are more completely broken down, or fermented, by bacteria in the colon than are insoluble fibers.[16,17] However, not all soluble fibers form viscous solutions, and some insoluble fibers are fermented.[16]

Soluble fibers are found around and inside plant cells. They include pectins, gums, some hemicelluloses, indigestible oligosaccharides, and **resistant starch**.[17] Some of the foods that contain soluble fibers include oats, apples, beans, and seaweed. Insoluble fibers are primarily derived from the structural parts of plants, such as the cell walls, and include cellulose, some hemicelluloses, and lignins. Food sources of insoluble fibers include wheat bran and rye bran, which are mostly hemicellulose and cellulose, and vegetables such as broccoli, which contain woody fibers composed partly of lignins. Most foods of plant origin contain mixtures of soluble and insoluble fibers (Figure 4.8).

In addition to dietary fiber found naturally in whole grains, fruits, and vegetables, fiber is added to food. Some fiber, referred to as functional fiber, is isolated and purified and added to foods and supplements for its beneficial physiological effects.[18] For example, wheat bran is an insoluble fiber that is added to breads and muffins to reduce their calorie content and meet consumer demand for high-fiber foods. Some fibers are added to foods to change their physical properties. For example, pectin is a soluble fiber found in fruits and vegetables that forms a gel when sugar and acid are added. It is used to thicken yogurt and to form jams and jellies. Carbohydrate gums such as xanthan gum and locust-bean gum are also soluble fibers that are used to keep gravies, puddings, and salad dressings from separating. Pectins and gums are also used to mimic the texture of fat in the production of reduced-fat products (see Chapter 5).

4.3 Carbohydrates in the Digestive Tract

LEARNING OBJECTIVES

- Describe the process of carbohydrate digestion.
- Explain why lactose intolerance causes gas and bloating when milk is consumed.
- Discuss the effects of dietary fiber on gastrointestinal function and health.

Disaccharides and complex carbohydrates must be digested to monosaccharides to be absorbed. Some people are unable to digest the disaccharide lactose: It spills into the colon, causing uncomfortable side effects. All humans lack the digestive enzymes needed to break down fibers. These indigestible carbohydrates have important effects on the health and function of the digestive system and the body as a whole.

Carbohydrate Digestion and Absorption

Digestion of carbohydrate begins in the mouth, where the enzyme salivary amylase starts breaking starch into shorter polysaccharides. The majority of starch and disaccharide digestion occurs in the small intestine. Here, pancreatic amylases complete the job of breaking down starch into disaccharides and oligosaccharides. The digestion of disaccharides and oligosaccharides is completed by enzymes attached to the microvilli in the small intestine (Figure 4.9). Here maltose is broken down into two glucose molecules by the enzyme maltase, sucrose is broken down by sucrase to yield glucose and fructose, and lactose is broken down by **lactase** to form glucose and galactose. The resulting monosaccharides—glucose, galactose, and fructose—are then absorbed and transported to the liver via the hepatic portal vein.

lactase An enzyme located in the microvilli of the small intestine that breaks the disaccharide lactose into glucose and galactose.

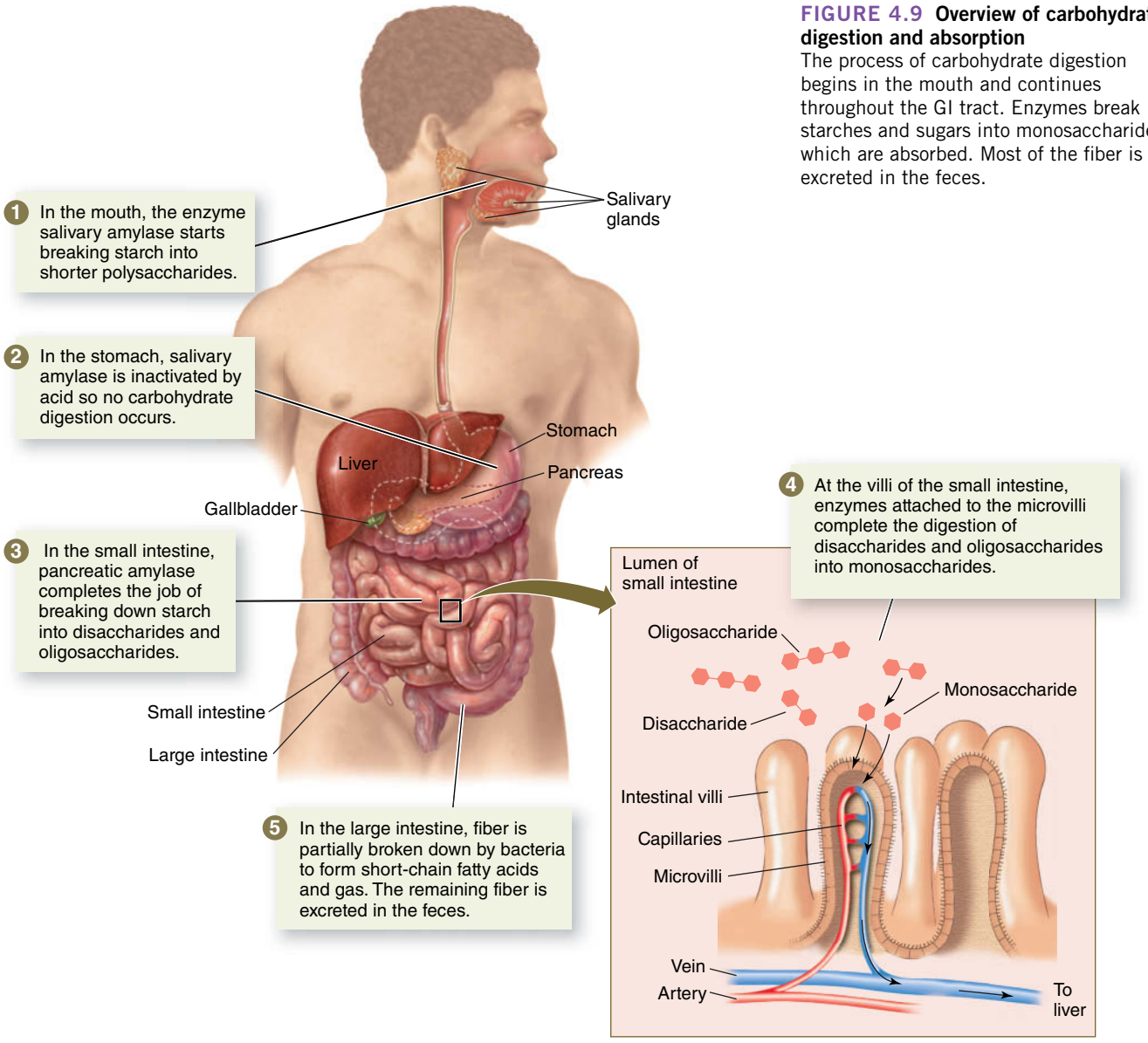


FIGURE 4.9 Overview of carbohydrate digestion and absorption
The process of carbohydrate digestion begins in the mouth and continues throughout the GI tract. Enzymes break starches and sugars into monosaccharides, which are absorbed. Most of the fiber is excreted in the feces.

Lactose Intolerance

lactose intolerance A condition in which people have digestive symptoms such as intestinal gas, bloating, and diarrhea after dairy products are consumed.

Lactose intolerance is a condition in which symptoms including abdominal distention, flatulence, cramping, and diarrhea develop after the consumption of dairy products. It occurs when there is not enough of the enzyme lactase in the small intestine to digest the milk sugar lactose.[19] When individuals with lactose intolerance consume dairy products, the lactose is not digested and cannot be absorbed. It passes into the large intestine where the increase in the number of small molecules draws water in by osmosis. The lactose is rapidly metabolized by intestinal bacteria, producing acids and gas. Together, the increase in fluid along with the acids and gas causes symptoms. In some people, symptoms occur only when they consume foods containing a large amount of lactose such as milk or ice cream. In others, symptoms occur even with consumption of foods containing small amounts of lactose, such as baked goods or snack foods.

How Common Is Lactose Intolerance? Most infants produce enough of the enzyme lactase to digest the lactose in milk, but in many people the enzyme's activity decreases with age. Lactose intolerance is uncommon in children under age 6, but becomes more prevalent with age. Approximately 65% of the adult human population has a reduced ability to digest lactose; incidence varies from less than 5% in Northern Europeans to near 90% in some East Asian populations. It is more common in African Americans, Native Americans, Hispanic Americans, and Asian Americans than it is in European Americans (Figure 4.10).[20,21] Lactose intolerance may also occur as a result of an intestinal infection or other disease. This secondary lactase deficiency may disappear when the other condition is resolved.

How People with Lactose Intolerance Can Meet Calcium Needs In the United States, dairy products are a main source of calcium; the Dietary Guidelines recommend 3 cups of low-fat milk or milk products each day.[14,22] Without dairy products, it can be difficult to get enough calcium. Some people with lactose intolerance can consume small amounts of dairy products without symptoms and so can meet their calcium needs by dividing the 3 cups into many smaller portions throughout the day. Those who are more sensitive to lactose can meet their calcium needs with foods like tofu, fish, vegetables, and fermented dairy products. These foods provide dietary calcium in cultures where lactose intolerance is common. For example,

THINK CRITICALLY

How do you think a high incidence of lactose intolerance would affect the traditional diet of a region?

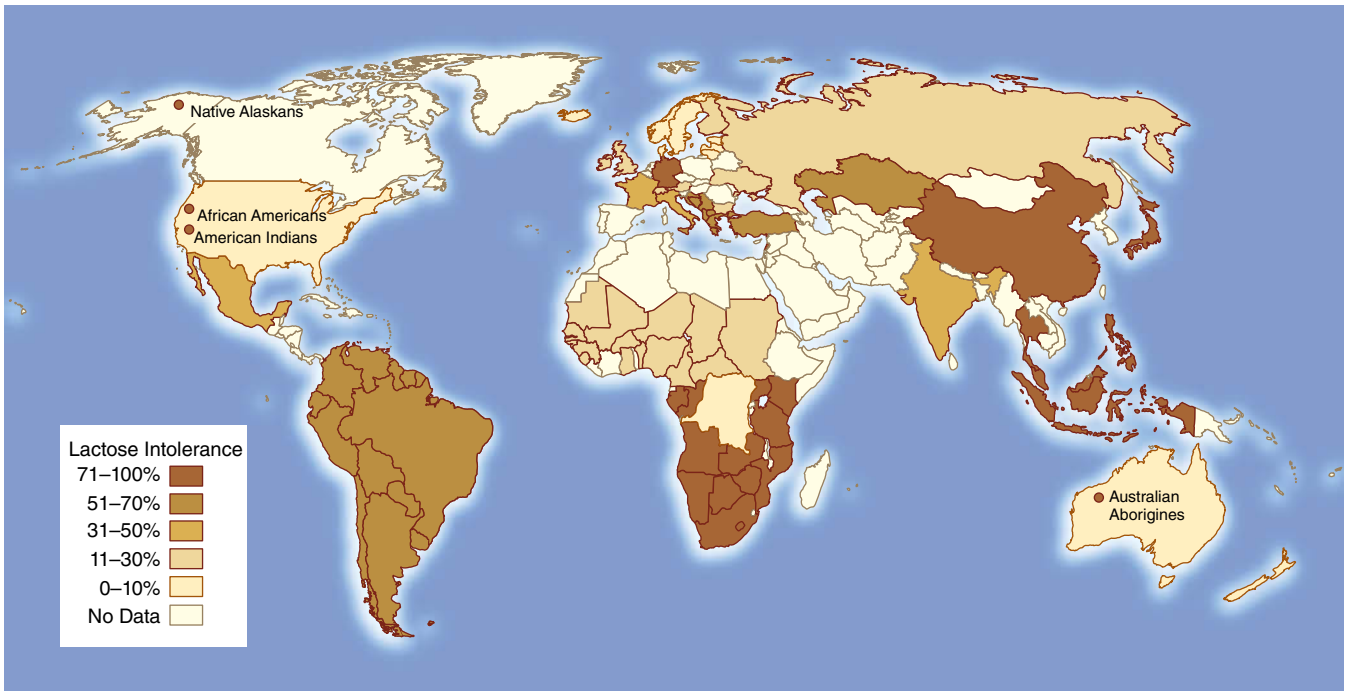


FIGURE 4.10 Incidence of lactose intolerance
The incidence of lactose intolerance around the world varies dramatically. Whether or not individuals retain the ability to digest lactose into adulthood depends on their racial and ethnic background.

in Asia, tofu and fish consumed with bones supply calcium, and in the Near East, cheese and yogurt provide much of the calcium. These fermented products are more easily tolerated than milk because some of the lactose originally present is digested by bacteria or lost in processing. Calcium-fortified foods, calcium supplements, milk treated with the enzyme lactase, and lactase tablets, which can be consumed with or before milk products, are also available for those with lactose intolerance.

Fiber in the Digestive Tract

Fiber is not digested and is therefore not readily absorbed. Some fibers such as cellulose and oligosaccharides are not digested because human enzymes cannot break the bonds that hold their subunits together. Resistant starch is not digested because the natural structure of the grain protects it, because cooking and processing alter its digestibility, or because it has intentionally been modified to resist digestion. For instance, heating makes potato starch more digestible, but cooling the cooked potato reduces the starch's digestibility. Legumes, unripe bananas, and cooked potatoes, rice, and pasta that have been allowed to cool are high in resistant starch. The presence of fiber in the diet affects GI function, the intestinal microbiota, the amount of intestinal gas, and nutrient absorption.

How Fiber Affects GI Function Fiber increases the weight of material in the lumen of the intestine. The extra weight is due to the bulk of the fiber itself, the water held by the fiber, and the increase in the number of bacteria.[16] The result is a larger, softer stool, which promotes healthy bowel function by stimulating peristalsis. More peristalsis causes the muscles of the colon to work more, become stronger, and function better, helping to ease evacuation of the stool and prevent constipation. The increase in peristalsis also reduces transit time—the time it takes food and fecal matter to move through the digestive tract. In African countries, where the diet contains 40 to 150 g of fiber per day, the transit time is 36 hours or less. In the United States, where the usual fiber intake is only about 15 g/day,[23] it is not uncommon for transit time to be as long as 96 hours (Figure 4.11).

Why Fiber Promotes a Healthy Microbiota When fermentable fibers reach the colon, they are broken down by the bacteria that reside there. This produces short-chain fatty acids, which serve as a fuel source for cells in the colon and are absorbed into the bloodstream where they provide energy to other body cells and may play a role in regulating cellular processes. These short-chain fatty acids also make the colonic contents more acidic, which inhibits the growth of undesirable bacteria and favors the growth of beneficial species of bacteria, such as *Lactobacilli* and *Bifidobacteria*, that are well adapted to acid conditions. In addition to inhibiting the growth of disease-causing bacteria, these beneficial bacteria and their metabolic by-products may help prevent inflammation in the bowel and potentially protect against colon cancer.[25,26]

Why Fiber Increases Intestinal Gas Anyone who has ever eaten beans knows of their potentially embarrassing side effect of flatulence. Beans cause gas because they are particularly high in the oligosaccharides raffinose and stachyose, which cannot be digested by enzymes in the human stomach and small intestine. They pass into the large intestine, where the bacteria that live there digest them, producing gas and other by-products. This gas can cause abdominal discomfort and flatulence. To alleviate the problem, over-the-counter enzyme tablets and solutions (such as Beano®) can be consumed to break down oligosaccharides before they reach the intestinal bacteria, thereby reducing the amount of gas produced.

Intestinal gas is also a by-product of the bacterial fermentation of other fibers. The amount of gas produced depends on the type of fiber and the amount consumed. A sudden increase in the fiber content of the diet can cause abdominal discomfort, gas, and diarrhea. Constipation can also be a problem if fiber intake is increased without

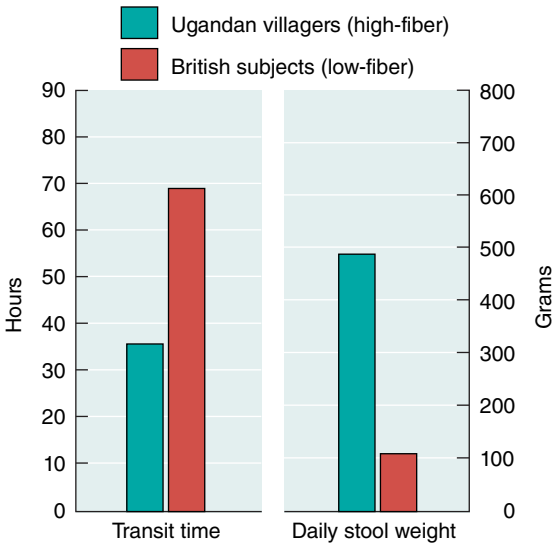


FIGURE 4.11 The effect of fiber on stool weight and transit time
In a study done in Africa, Ugandan villagers who consumed a diet high in fiber were compared to British subjects living in Uganda who consumed a more refined, low-fiber diet. Stool weights were greater and transit times shorter for Ugandan villagers than for British subjects.[24]

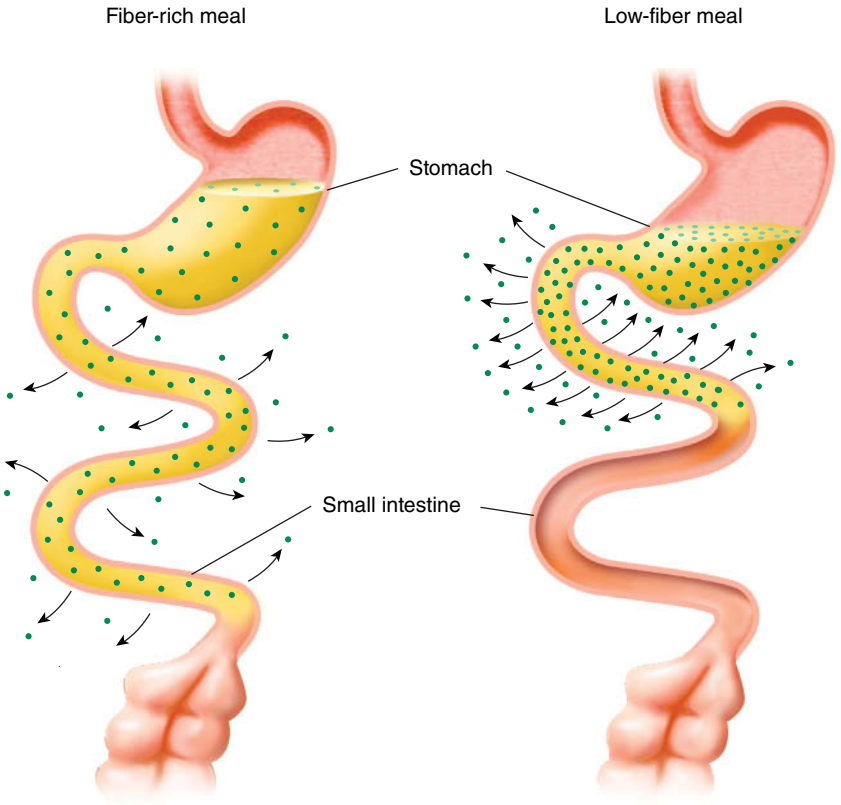


FIGURE 4.12 Fiber slows digestion and absorption
As shown on the left, the bulk and volume of a fiber-rich meal dilute the gastrointestinal contents. This dilution slows the digestion of food and absorption of nutrients (shown as green dots moving slowly out of the intestine). With a low-fiber meal, as shown on the right, nutrients are more concentrated; digestion and absorption occur more rapidly (shown as green dots moving quickly out of the intestine).

an increase in fluid intake. To avoid these problems, the fiber content of the diet should be increased gradually and fluid intake should be increased along with it.

How Fiber Affects Nutrient Absorption Fiber binds certain minerals, preventing their absorption. For instance, wheat bran fiber binds the minerals zinc, calcium, magnesium, and iron. Too much fiber can reduce the absorption of these essential minerals. However, when mineral intake meets recommendations, a reasonable intake of high-fiber foods does not compromise mineral status.

The added bulk provided by fiber slows overall nutrient absorption, in part by slowing stomach emptying. This is beneficial for people who are trying to lose weight because they may feel satiated after fewer calories are consumed.[27] However, a high-fiber diet may be a disadvantage for people with a small stomach capacity because they may satisfy their hunger before their nutrient requirements are met. Generally, this is a problem only when the diet is low in protein or micronutrients or when high-fiber diets are consumed by young children, whose small stomachs limit the amount of food they can eat.

Once in the small intestine, fiber slows nutrient digestion and absorption because it increases the volume of the intestinal contents and absorbs water, forming viscous solutions. This speeds passage through the GI tract, reduces contact between digestive enzymes and food, and decreases the amount of contact between nutrients and the absorptive surface of the small intestine, all of which slow the absorption of glucose and other nutrients (Figure 4.12).

4.4 Carbohydrates in the Body

LEARNING OBJECTIVES

- Name the main function of glucose in the body.
- Discuss factors that affect blood glucose levels after eating and when fasting.
- Describe the steps involved in metabolizing glucose to produce ATP.
- Explain how metabolism changes when carbohydrate is limited.

Carbohydrate is an important source of energy for body cells. Some cells, such as those in the brain, rely almost exclusively on glucose for energy. It is therefore important to regulate levels of glucose in the blood to ensure adequate glucose delivery to cells. Once inside body cells, glucose can be completely oxidized and the energy it contains used to synthesize ATP.

Carbohydrate Functions

The main function of glucose is to provide energy to body cells, but carbohydrates also provide other essential functions. The monosaccharide galactose is an important molecule in nervous tissue. It also combines with glucose to make lactose in women who are producing breast milk. Deoxyribose and ribose are monosaccharides that are components of DNA and RNA (ribonucleic acid), respectively, the two molecules that contain a cell's genetic information. Deoxyribose and ribose can be synthesized by the body and are not found in significant amounts in the diet. Ribose is also a component of the vitamin riboflavin. Oligosaccharides are also important in our bodies. They are attached to proteins or lipids on the surface of cells, where they help to signal information about the cells. Glycogen provides a storage form of glucose. Another type of carbohydrate that is important in the body is mucopolysaccharides. They are a type of polysaccharide that functions with proteins in body secretions and structures. Mucopolysaccharides give mucus its viscous consistency and provide cushioning and lubrication in connective tissue.

Delivering Glucose to Body Cells

After absorption, glucose and other monosaccharides travel to the liver via the hepatic portal vein. Here fructose and galactose are metabolized for energy. Glucose may be broken down by the liver to provide energy or stored as glycogen, but most is passed into the general blood circulation, causing blood glucose levels to rise. Glucose delivered in the blood provides energy to body cells. Many body cells can use energy sources other than glucose, such as fatty acids, but brain cells, red blood cells, and a few others must have glucose to stay alive. To provide a steady supply of glucose, the concentration of glucose in the blood is regulated by the liver and by hormones secreted by the pancreas.

glycemic response The rate, magnitude, and duration of the rise in blood glucose that occurs after a particular food or meal is consumed.

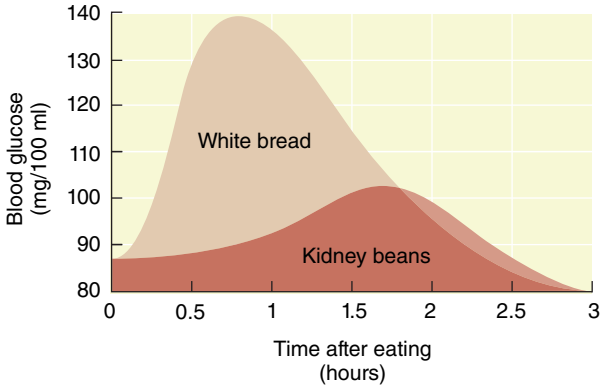
glycemic index A ranking of the effect on blood glucose of a food of a certain carbohydrate content relative to an equal amount of carbohydrate from a reference food such as white bread or glucose.

What Affects Glycemic Response? How quickly and how high blood glucose rises after carbohydrate is consumed is referred to as **glycemic response**. This response is affected by both the amount and type of carbohydrate eaten and the amount of fat and protein in that food or meal. Because carbohydrate must be digested and absorbed to enter the blood, how quickly a food leaves the stomach and how fast it is digested and absorbed in the small intestine affect how long it takes glucose to get into the blood.

Refined sugars and starches generally cause a greater glycemic response than unrefined carbohydrates that contain fiber. This is because sugars and starches consumed alone leave the stomach quickly and are rapidly digested and absorbed, causing a sharp, swift rise in blood sugar. For example, when you drink a can of soda or eat a slice of white bread on an empty stomach, your blood sugar increases within minutes. Eating a high-fiber food causes a slower, lower increase in blood sugar (Figure 4.13). The presence of fat and protein also slows stomach emptying, and therefore foods high in these macronutrients generally cause a smaller glycemic response than foods containing sugar or starch alone. For example, ice cream is high in sugar but also contains fat and some protein, so it causes a smaller rise in blood glucose than sorbet, which contains sugar but no fat or protein.

The glycemic response of a specific food can be quantified by its **glycemic index**. Glycemic index is a ranking of how a food affects blood glucose compared to the response of an equivalent amount of carbohydrate from a reference food such as white bread or pure glucose. The reference food is assigned a value

FIGURE 4.13 Effect of refined and unrefined carbohydrates on blood glucose levels
Blood glucose rises higher and more rapidly after a person eats white bread than it does after the person eats an equivalent amount of carbohydrate from kidney beans. The kidney beans contain fiber and are higher in protein than the bread. Both slow digestion and absorption and reduce glycemic response.



ANALYZE THE DATA

How would the graph of blood glucose levels after eating a peanut butter sandwich differ from the graph shown here for just the bread?

of 100 and the values for other foods are expressed relative to this. Foods that have a glycemic index of 70 or more compared to glucose are considered high-glycemic-index foods; those with an index of less than 55 are considered low-glycemic-index foods.

The glycemic index can be used to evaluate the effect of a specific food on blood glucose, but it is not based on amounts of carbohydrate in a typical portion of food. For example, watermelon has a high glycemic index, but this is based on a larger piece of watermelon than is typically consumed. The actual rise in blood glucose after eating a slice of watermelon is not large. **Glycemic load** is a method of assessing glycemic response that takes into account both the glycemic index of the food and the amount of carbohydrate in a typical portion. To calculate glycemic load, the grams of available carbohydrate in a serving of food are multiplied by that food's glycemic index expressed as a percentage. A glycemic load of 20 or more is considered high, whereas a value of less than 11 is considered low.

glycemic load An index of the glycemic response that occurs after eating specific foods. It is calculated by multiplying a food's glycemic index by the amount of available carbohydrate in a serving of the food.

A shortcoming of both the glycemic index and glycemic load is that they are determined for individual foods, but we typically eat meals containing mixtures of foods. Knowing the glycemic index or glycemic load of a specific food does not tell us much about what blood glucose levels will be after eating this food as part of a mixed meal. For example, a bowl of white rice has a high glycemic index and glycemic load, but if the rice is part of a meal that contains chicken and broccoli, the rise in blood glucose will be much lower than if the rice were consumed by itself.

insulin A hormone secreted by the pancreas that allows the uptake of glucose by muscle and adipose tissue and has other metabolic effects such as stimulating protein and fat synthesis and the synthesis of glycogen in liver and muscle.

Supplying Glucose to Body Cells

To provide energy, glucose in the bloodstream must enter cells. A rise in blood glucose triggers the pancreas to secrete the hormone **insulin**, which allows glucose to be taken into muscle and adipose tissue cells. In the liver, insulin promotes the storage of glucose as glycogen and, to a lesser extent, fat. In muscle, it stimulates not only the uptake of glucose for ATP production but also the synthesis of muscle glycogen for energy storage (Figure 4.14). Insulin also stimulates protein synthesis, and in fat-storing cells, it stimulates lipid synthesis. These actions remove glucose from the blood, decreasing its level.

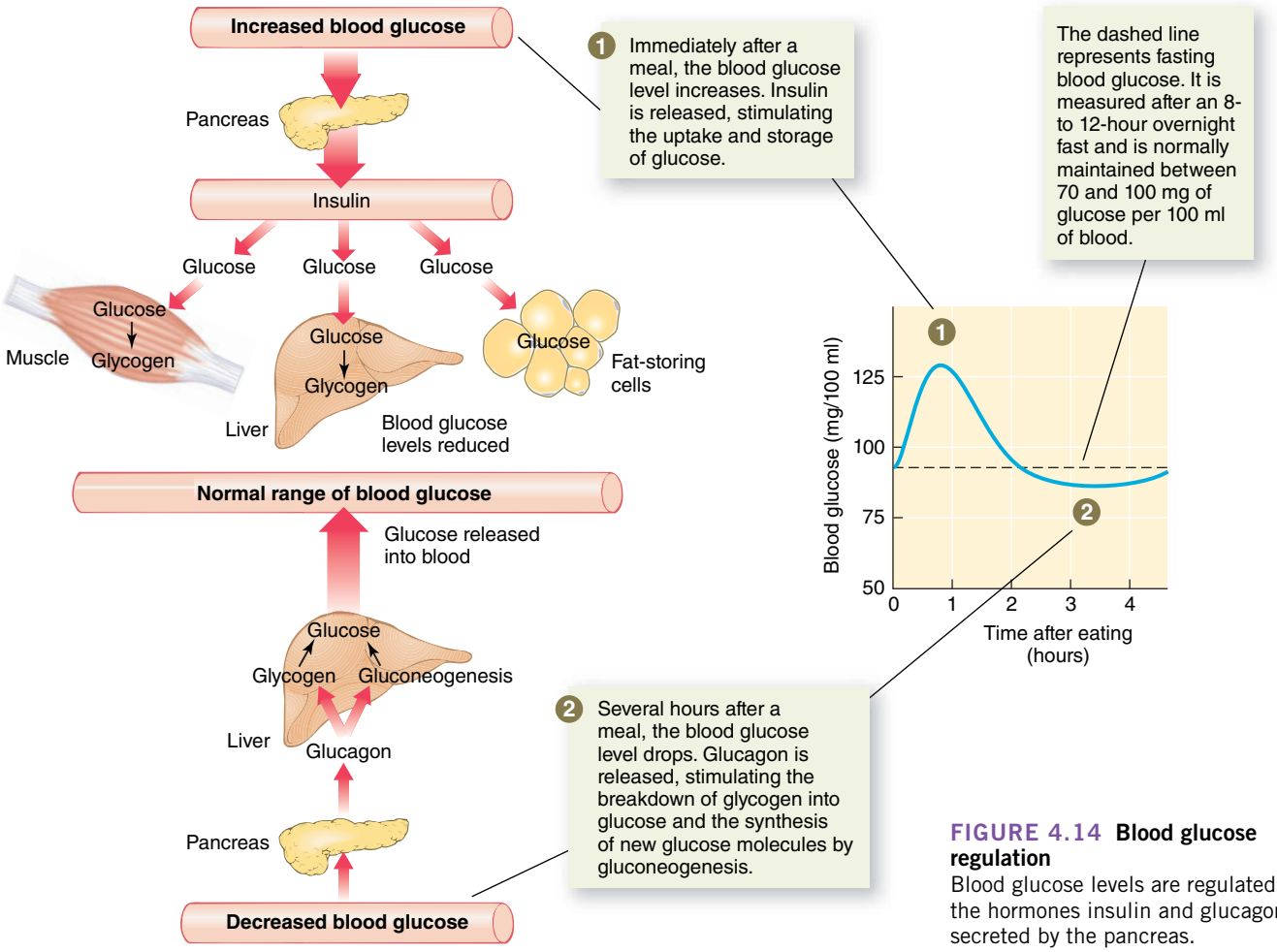


FIGURE 4.14 Blood glucose regulation
Blood glucose levels are regulated by the hormones insulin and glucagon, secreted by the pancreas.

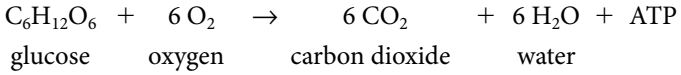
When no carbohydrate has been consumed for a few hours, the glucose level in the blood—and consequently the glucose available to the cells—begins to decrease. This triggers the pancreas to secrete the hormone **glucagon**. Glucagon signals liver cells to break down glycogen into glucose, which is released into the bloodstream. Glucagon also stimulates the liver to synthesize new glucose molecules by **gluconeogenesis** (see Figure 4.14). Newly synthesized glucose is released into the blood to prevent blood glucose from dropping below the normal range. Gluconeogenesis can also be stimulated by the hormone epinephrine, also known as adrenaline. This hormone, which is released in response to dangerous or stressful situations, enables the body to respond to emergencies. It causes a rapid release of glucose into the blood to supply the energy needed for action.

glucagon A hormone secreted by the pancreas that stimulates the breakdown of liver glycogen and the synthesis of glucose to increase blood sugar.

gluconeogenesis The synthesis of glucose from simple noncarbohydrate molecules. Amino acids from protein are the primary source of carbons for glucose synthesis.

How Glucose Provides Energy

Once glucose reaches body cells, it can be metabolized through **cellular respiration** to generate ATP. Cellular respiration uses 6 molecules of oxygen to oxidize 1 molecule of glucose, forming 6 molecules of carbon dioxide, 6 molecules of water, and about 38 molecules of ATP:



cellular respiration The reactions that break down carbohydrates, fats, and proteins in the presence of oxygen to produce carbon dioxide, water, and ATP.

The carbon dioxide produced by cellular respiration is transported to the lungs, where it is eliminated in exhaled air. Providing energy through cellular respiration involves four interconnected stages.

Glycolysis The first stage of cellular respiration takes place in the cytosol of the cell and is called **glycolysis**, meaning glucose breakdown. Because oxygen isn't needed for this reaction, glycolysis is sometimes called **anaerobic metabolism**. In glycolysis, the six-carbon sugar glucose is broken into 2 three-carbon molecules called pyruvate (Figure 4.15). The reactions generate two molecules of ATP for each molecule of glucose and release high-energy electrons that are passed to shuttling molecules, which can transport them to the last stage of cellular respiration. When oxygen is limited, no further metabolism of glucose and production of ATP occur (see online Focus on Metabolism).

glycolysis (also called **anaerobic metabolism**). Metabolic reactions in the cytosol of the cell that split glucose into 2 three-carbon pyruvate molecules, yielding two ATP molecules.

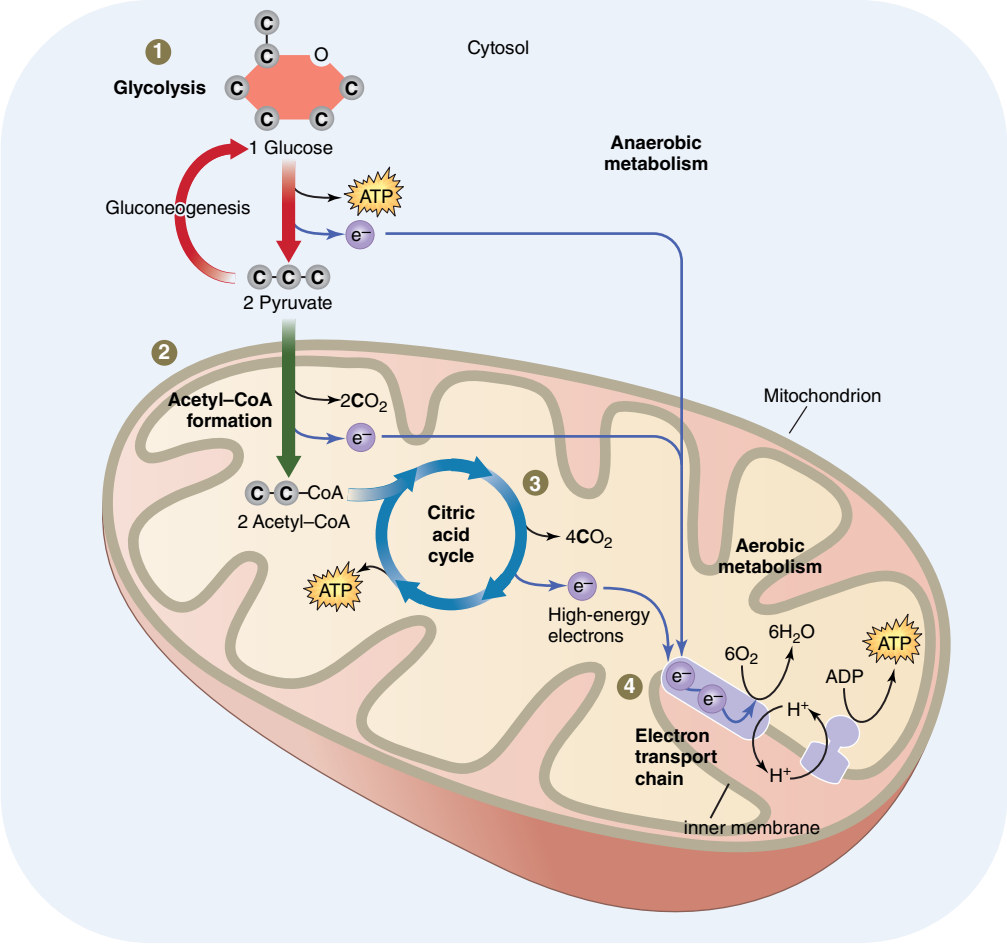
Acetyl-CoA Formation When oxygen is present, **aerobic metabolism** can proceed. In the mitochondria, one carbon is removed from pyruvate and released as CO_2. The remaining two-carbon compound combines with a molecule of coenzyme A (CoA) to form acetyl-CoA (see Figure 4.15). High-energy electrons are released and passed to shuttling molecules for transport to the last stage of cellular respiration. Acetyl-CoA then enters the third stage of cellular respiration, the citric acid cycle.

aerobic metabolism Metabolism in the presence of oxygen, which can completely break down glucose to yield carbon dioxide, water, and as many as 38 ATP molecules.

Citric Acid Cycle In the third stage, acetyl-CoA combines with oxaloacetate, a four-carbon molecule derived from carbohydrate, to form a six-carbon molecule called citric acid and begin the citric acid cycle (see Figure 4.15). The reactions of the citric acid cycle then remove one carbon at a time, to produce carbon dioxide. After two carbons have been removed in this manner, a four-carbon oxaloacetate molecule is re-formed and the cycle can begin again. These chemical reactions produce two ATP molecules per glucose molecule and also remove electrons, which are passed to shuttling molecules for transport to the fourth and last stage of cellular respiration, the electron transport chain.

Electron Transport Chain The electron transport chain consists of a series of molecules, most of which are proteins, associated with the inner membrane of the mitochondria. These molecules accept electrons from the shuttling molecules and pass them from one to another down the chain until they are finally combined with oxygen to form water (see Figure 4.15). As the electrons are passed along, their energy is used to pump hydrogen ions across the inner mitochondrial membrane. As the hydrogen ions flow back across the membrane, the energy is trapped and used to add a phosphate group to ADP, forming ATP. The reactions of cellular respiration are central to all energy-yielding processes in the body.

FIGURE 4.15 Cellular respiration: providing energy from glucose
The reactions of cellular respiration split the bonds between carbon atoms in glucose, releasing energy that is used to add a phosphate to ADP, to form ATP. ATP is used to power the energy-requiring processes in the body.



1. In the cytosol of the cell, glycolysis splits glucose, a six-carbon molecule, into two molecules of pyruvate, a three-carbon molecule. This step produces high-energy electrons (e^-) and two molecules of ATP per glucose. Each pyruvate is then either broken down to produce more ATP or used to make glucose via gluconeogenesis.
2. When oxygen is available, pyruvate can be used to produce more ATP. The first step is to remove one carbon as carbon dioxide from each pyruvate. This produces a two-carbon molecule that combines with coenzyme A to form acetyl-CoA and releases high-energy electrons.
3. Acetyl-CoA enters the citric acid cycle, where two carbons are lost as carbon dioxide, high-energy electrons are released, and a small amount of ATP is produced.
4. Most ATP is produced in the final step of cellular respiration, the electron transport chain. Here, the energy from the high-energy electrons released in previous steps pumps hydrogen ions across the inner mitochondrial membrane. As the hydrogen ions flow back, the energy is used to convert ADP to ATP. The electrons are combined with oxygen and hydrogen to form water.

What Happens When Carbohydrate Is Limited?

Even when carbohydrate intake is low, blood glucose levels must be maintained in the normal range in order to fuel the brain. Low levels of glucose in the brain cause confusion, seizures, and eventually coma. To maintain blood glucose in the normal range when carbohydrate intake is low, glucose can be obtained from the breakdown of glycogen and from the synthesis of new glucose by gluconeogenesis.

glucogenic amino acid An amino acid that can be used to synthesize glucose through gluconeogenesis.

ketogenic amino acid An amino acid that breaks down to form acetyl-CoA and thus contributes to ketone synthesis.

Why Protein Is Broken Down to Supply Blood Glucose Gluconeogenesis, which occurs in liver and kidney cells, is an energy-requiring process that synthesizes glucose from three-carbon molecules. These three-carbon molecules come primarily from amino acids derived from protein breakdown. When metabolized, some amino acids, referred to as **glucogenic amino acids**, form pyruvate or oxaloacetate, which can then be used to make glucose (Figure 4.16). Fatty acids and **ketogenic amino acids** cannot be used to make glucose because the reactions that break them down produce two-carbon molecules that form acetyl-CoA. Gluconeogenesis is essential for meeting the body's immediate need for glucose, particularly when carbohydrate

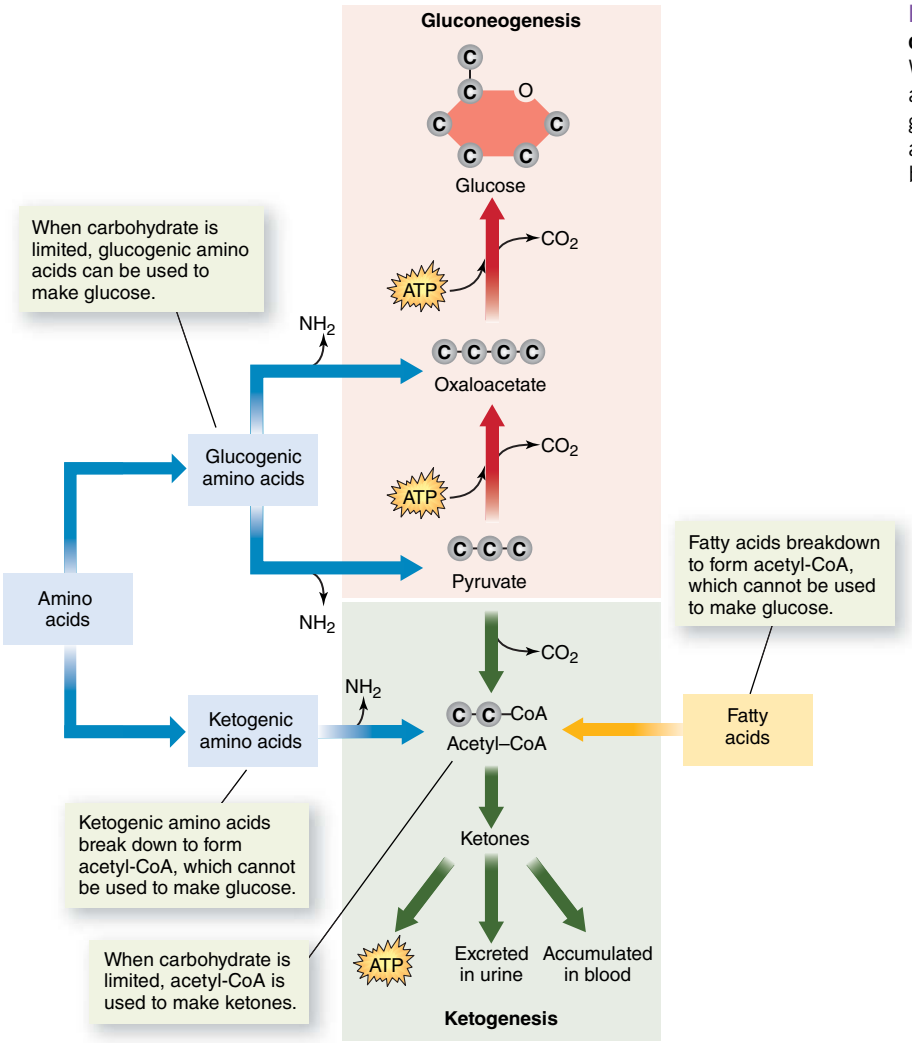


FIGURE 4.16 Metabolism when carbohydrate is limited
When carbohydrate is limited, glucogenic amino acids can be broken down to provide glucose. Fatty acids and ketogenic amino acids are used to make ketones, but cannot be used to synthesize glucose.

intake is very low, but it uses amino acids from proteins that could be used for other essential functions such as growth and maintenance of muscle tissue. Since adequate dietary carbohydrate eliminates the need to use amino acids from protein to synthesize glucose, carbohydrate is said to spare protein.

Why Ketones Are Formed To be metabolized via the citric acid cycle, acetyl-CoA must combine with a four-carbon oxaloacetate molecule. Oxaloacetate is derived from carbohydrate. When carbohydrate is in short supply, oxaloacetate is conserved, so acetyl-CoA cannot enter the citric acid cycle and be broken down to form carbon dioxide and water and produce ATP. Instead, the liver converts it into compounds known as **ketones** or **ketone bodies**, which are released into the blood (see Figure 4.16). When fatty acids (or ketogenic amino acids) are broken down for energy, they yield two-carbon molecules that form acetyl-CoA. Without carbohydrate, fatty acids and ketogenic amino acids cannot be completely oxidized and ketones are formed.

ketones or **ketone bodies** Molecules formed in the liver when the amount of carbohydrate is not sufficient to completely metabolize the two-carbon units produced from fat breakdown.

Ketone production is a normal response to starvation or to a diet very low in carbohydrate. Ketones can be used as an energy source by tissues, such as those in the heart, muscle, and kidney. After about three days of fasting, even the brain adapts and can obtain about half of its energy from ketones. The use of ketones for energy helps spare glucose and decreases the amount of protein that must be broken down to synthesize glucose.

Ketones not used for energy can be excreted by the kidney in urine. However, if ketone production is high, ketones can build up in the blood, causing **ketosis**. Mild ketosis can occur during starvation or when consuming a low-carbohydrate weight-loss diet and can cause symptoms such as reduced appetite, headaches, dry mouth, and odd-smelling breath. Severe ketosis can occur with untreated diabetes and, as discussed below, it can increase the blood's acidity so much that normal body processes cannot proceed, eventually causing coma and even death.

ketosis High levels of ketones in the blood.

4.5 Carbohydrates and Health

LEARNING OBJECTIVES

- Discuss the causes and health consequences of diabetes.
- Describe how carbohydrate intake contributes to the development of dental caries.
- Discuss the role of carbohydrates in weight management.
- Explain how fiber intake affects the risk of heart disease, diverticulitis, and colon cancer.

diabetes mellitus A disease caused by insufficient insulin production and/or decreased sensitivity of cells to insulin. It results in elevated blood glucose levels.

type 1 diabetes A form of diabetes that is caused by the autoimmune destruction of insulin-producing cells in the pancreas, usually leading to absolute insulin deficiency; previously known as insulin-dependent diabetes or juvenile-onset diabetes.

Are carbohydrates good for you or bad for you? They have been blamed for a host of chronic health problems, from diabetes to obesity, yet carbohydrate-rich foods are the basis of healthy diets around the world, and U.S. guidelines for a healthy diet recommend that people base their diet on carbohydrate-rich foods in order to reduce disease risk. The incongruity relates to the health effects of different forms and sources of dietary carbohydrates: A dietary pattern that is high in unrefined carbohydrates, such as whole grains, fruits, and vegetables, has been associated with a lower incidence of a variety of chronic diseases, whereas diets high in refined carbohydrates, such as added sugars and white flour, may contribute to chronic disease risk.[14,28]

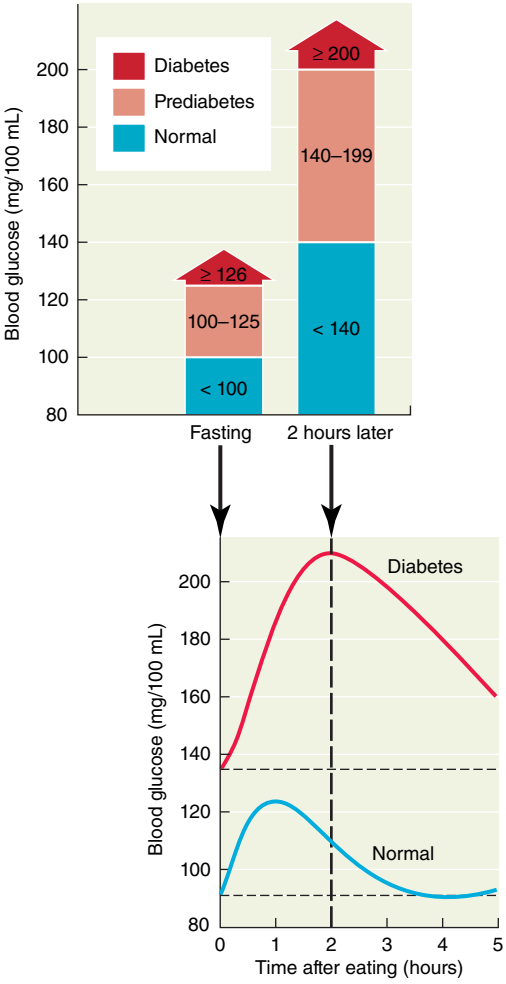


FIGURE 4.17 Blood glucose levels in diabetes
Blood glucose levels are elevated in diabetes. This graph compares levels measured after an eight-hour fast and two hours after consuming a test solution containing 75 g of glucose. The result can be used to determine whether an individual has normal blood glucose levels, prediabetes, or diabetes.

Diabetes Mellitus

Diabetes mellitus, commonly called diabetes, is a major public health problem in the United States. Diabetes affects 29.1 million Americans; more than 8 million of these do not know they have the disease. Annually, it is estimated to account for about $245 billion in direct medical costs and indirect costs due to disability, lost work, and premature death.[29] Diabetes is characterized by high blood glucose levels due to a lack of insulin and/or an unresponsiveness or resistance to insulin (Figure 4.17). There are three main types of diabetes: type 1; type 2; and gestational diabetes, which occurs during pregnancy.

Type 1 Diabetes **Type 1 diabetes** is an autoimmune disease in which the body's own immune system destroys the insulin-secreting cells of the pancreas. Once these cells are destroyed, insulin is no longer made in the body. Type 1 diabetes is usually diagnosed before the age of 30 and accounts for only 5 to 10% of diagnosed cases of diabetes. It is not known what causes the immune system to malfunction and attack its own cells, but genetics, viral infections, exposure to toxins, and abnormalities in the immune system have been hypothesized to play a role.

Type 2 Diabetes **Type 2 diabetes** is the more common form of diabetes. It accounts for 90 to 95% of all cases of diabetes in the United States. It occurs when the body does not produce enough insulin to keep blood glucose in the normal range. This can occur because body cells lose their sensitivity to insulin, a condition called *insulin resistance*, or when the amount of insulin secreted is reduced. When tissues are resistant to insulin, large amounts are required for cells to take up enough glucose to meet their energy needs. Type 2 diabetes is believed to be due to a combination of genetic and lifestyle factors. Risk of developing this disease is increased in people with a family history of diabetes; in those who are overweight, particularly if they carry their extra body fat in the abdominal region; and in those who have a sedentary lifestyle. Evidence is accumulating that the risk of developing type 2 diabetes is increased by diets high in refined carbohydrates.[30] The incidence of type 2 diabetes is higher among

minority groups. Compared with non-Hispanic white adults, the incidence of diabetes is 18% higher among Asian Americans, 68% higher among Hispanics, and 74% higher among non-Hispanic blacks.[29] Type 2 diabetes may occur as part of a cluster of conditions called **metabolic syndrome** that includes obesity, elevated blood pressure, altered blood lipid levels, and insulin resistance.

Type 2 diabetes is often preceded by a condition called **prediabetes** or **impaired glucose tolerance** in which blood glucose levels are above normal but not high enough to be diagnosed as diabetes (see Figure 4.17). An estimated 86 million adults ages 20 years and older have prediabetes and are therefore at increased risk for developing diabetes, as well as heart disease and stroke.[29] Progression to diabetes among those with prediabetes is not inevitable. Weight loss and increased physical activity among people with prediabetes can prevent or delay diabetes and may return blood glucose levels to normal.

Type 2 diabetes has typically been diagnosed in people over the age of 40, but its incidence is increasing among younger individuals (Figure 4.18). This change is thought to be due to the increasing incidence of obesity and overweight in younger age groups. Before 1994, fewer than 5% of children with newly diagnosed diabetes were classified as type 2, but recently this has increased to more than 20%.[29]

type 2 diabetes A form of diabetes characterized by insulin resistance and relative insulin deficiency; previously known as non–insulin-dependent diabetes or adult-onset diabetes.

metabolic syndrome A collection of health risks, including high blood pressure, altered blood lipids, high blood glucose, and a large waist circumference, that increases the chance of developing heart disease, stroke, and diabetes. The condition is also called Syndrome X, insulin resistance syndrome, or dysmetabolic syndrome.

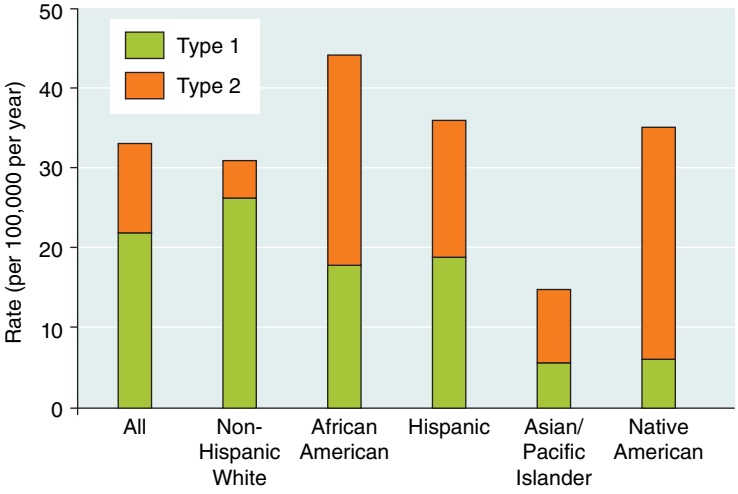
Gestational Diabetes

Gestational diabetes is a form of diabetes that occurs in women during pregnancy. It may be caused by the hormonal changes of pregnancy. The high levels of glucose in the mother's blood increase the risk of complications for the unborn child (see Chapter 14). Gestational diabetes usually disappears once the pregnancy is complete and hormones return to nonpregnant levels. However, individuals who have had gestational diabetes have an increased risk for developing type 2 diabetes later in life.

LIFE CYCLE

prediabetes or **impaired glucose tolerance** A fasting blood glucose level above the normal range but not high enough to be classified as diabetes.

gestational diabetes A form of diabetes that occurs during pregnancy and resolves after the baby is born.



© Jeff Greenberg/Alamy

ANALYZE THE DATA

Based on the graph and your knowledge of the connection between type 2 diabetes and obesity, which population group would you predict has the highest incidence of obesity?

FIGURE 4.18 Type 1 and type 2 diabetes in adolescents
This graph compares the number of cases of type 1 and type 2 diabetes diagnosed per year in adolescents (ages 10 to 19) by race/ethnicity.[29] Twenty years ago, type 2 diabetes was rare in this age group, but as in adults, the incidence is rising, especially in certain minority groups. Reducing type 2 diabetes in minority groups will require culturally sensitive strategies to modify diet and lifestyle.

Why Diabetes Causes Symptoms and Complications The symptoms and complications of diabetes result from the fact that, without sufficient insulin, glucose cannot be used normally. Cells that require insulin for glucose uptake are starved for glucose, and cells that can use glucose without insulin are exposed to damaging high levels.

Immediate Symptoms The immediate symptoms of diabetes may include excessive thirst, frequent urination, blurred vision, and weight loss. Excessive thirst and frequent urination occur because blood glucose levels rise so high that the kidneys excrete glucose, which draws water with it, increasing the volume of urine. Blurred vision occurs when excess glucose enters the lens of the eye, drawing in water and causing the lens to swell. Weight loss occurs because glucose cannot enter muscle and adipose tissue cells to be used for energy, so the body responds as it does in starvation, breaking down fat and protein to supply fuel. With limited carbohydrate available for fatty acid metabolism, ketones are formed and released into the blood. Some ketones are used as fuel by muscle and adipose tissue, but in type 1 diabetes, they are produced more rapidly than they can be used and thus accumulate in the blood. This elevation of ketones causes an increase in the acidity of the blood called *ketoacidosis*. In type 2 diabetes, ketoacidosis usually does not develop because there is enough insulin to allow some glucose to be used, so fewer ketones are produced.

Long-Term Complications The long-term complications of diabetes include damage to the heart, blood vessels, kidneys, eyes, and nerves. This damage is thought to be a result of prolonged exposure to high levels of blood glucose. When glucose is high it can bind to proteins, contributing to blood vessel damage and abnormalities in blood cell function. Damage to the large blood vessels leads to increased risk of heart disease and stroke. Compared to adults without diabetes, the death rate for heart disease is 1.7 times higher and hospitalization rates for stroke are 1.5 times higher among people with diabetes.[29] Heart disease is the leading cause of premature death among people with diabetes. High blood glucose also causes changes in small blood vessels and nerves that lead to kidney failure, blindness, and nerve dysfunction. In the United States, diabetes is the leading cause of blindness in adults and accounts for 44% of all new cases of kidney failure and more than 60% of nontraumatic lower-limb amputations[29] (Figure 4.19).

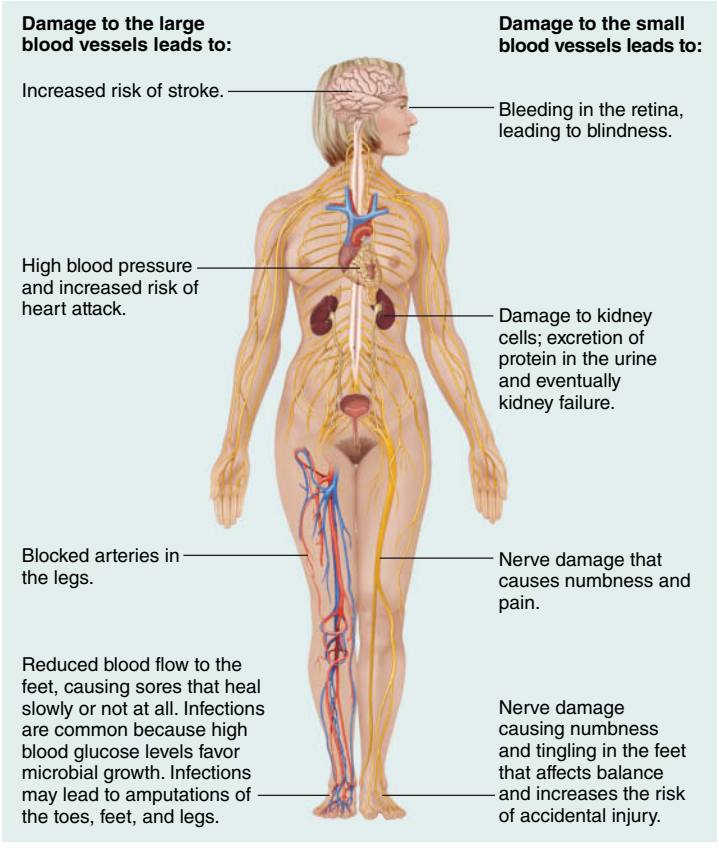


FIGURE 4.19 Diabetes complications
The long-term complications of diabetes result from damage to both the large blood vessels, which leads to an increased risk of heart attack and stroke, and changes in small blood vessels, which can cause blindness, kidney failure, and nerve dysfunction.

How Diabetes Is Managed The goal of diabetes management is to keep blood glucose levels within the normal range. This involves diet, exercise, and, in many cases, medication (Figure 4.20). Blood glucose levels should be monitored frequently to ensure that levels are staying in the healthy range. Adherence to this type of treatment regimen can reduce the incidence of elevated blood glucose levels and the complications it causes. To reduce disability and death associated with diabetes and its complications, the National Institutes of Health and the Centers for Disease Control and Prevention have established the National Diabetes Education Program. This program is designed to increase public awareness of the seriousness of diabetes, promote better management among individuals with diabetes, and improve the quality of and access to health care.[31]

Diet Individuals with diabetes need to moderate their carbohydrate intake to prevent large fluctuations in blood glucose. Typically this is done using a system called *carbohydrate counting* to estimate and control the amount of carbohydrate consumed with each meal. The diet should also be adequate in energy, protein, and micronutrients. Carbohydrate should provide 40 to 50% of energy with an emphasis on unrefined carbohydrates,

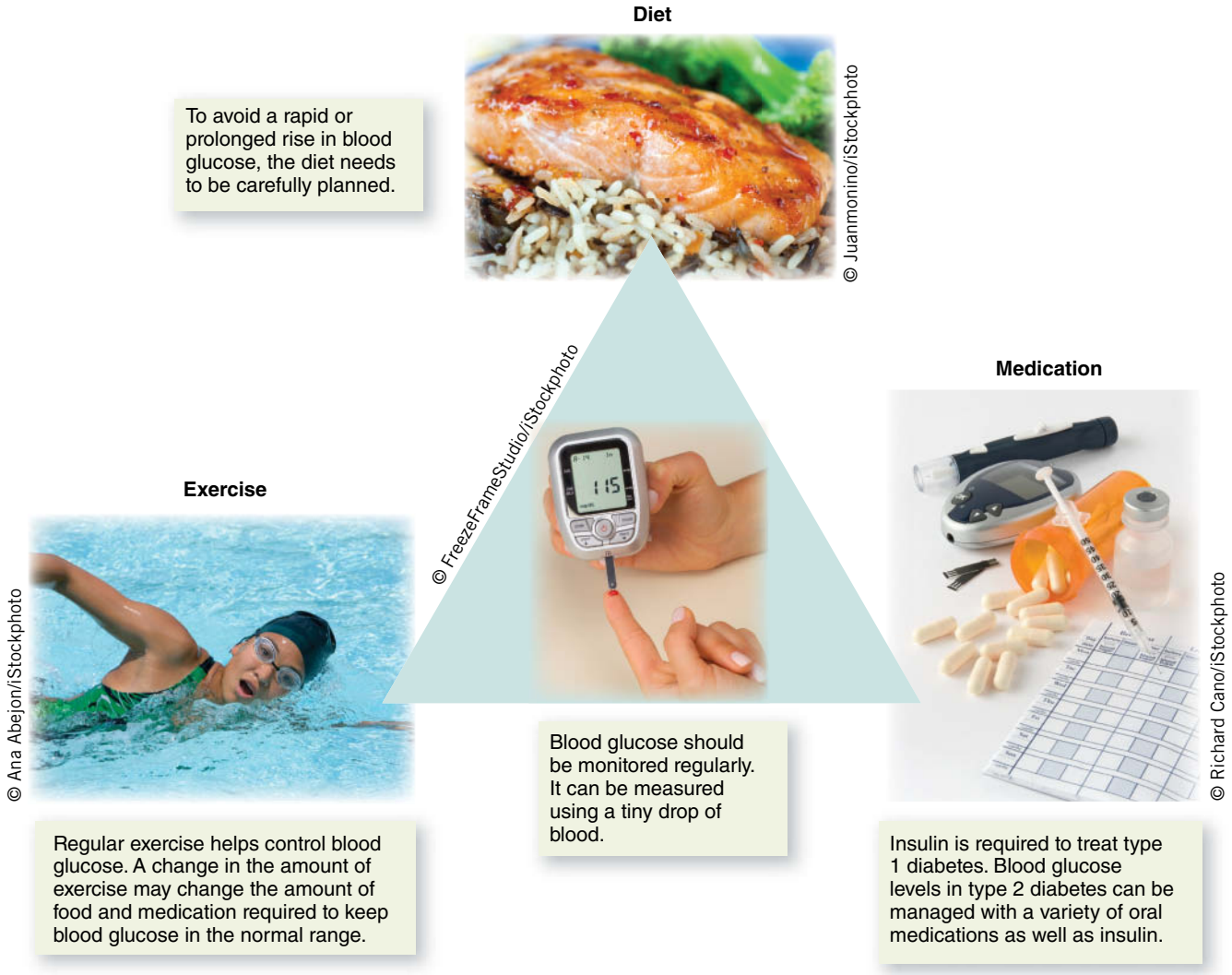


FIGURE 4.20 Diabetes management
The management of diabetes requires controlling blood glucose levels with diet, exercise, and, in many cases, medication. Carbohydrate intake must be coordinated with medication and exercise schedules so that glucose and insulin are available in the proper proportions at the same time to maintain normal blood glucose levels.[33]

which do not cause a rapid rise in blood glucose. To help prevent heart disease, fat intake should be limited to no more than 30% of energy, with no more than 10% from saturated fat. Overweight individuals may need to restrict energy intake to promote weight loss, which can be beneficial for maintaining blood glucose levels in the normal range.

Exercise Exercise is an important component of diabetes management. Exercise increases the sensitivity of body cells to insulin so that glucose is available to fuel exercising muscles. Exercise also promotes weight loss, which further reduces insulin resistance. In people with diabetes, both aerobic and resistance exercise have been shown to improve glucose tolerance and insulin sensitivity and to lower blood glucose levels.[32] Exercise can also help to lower blood pressure, thereby reducing heart disease risk. Exercise patterns must be coordinated with meal and medication schedules to ensure that glucose is available during exercise.

Medication When diet and exercise cannot keep blood glucose in the normal range, drug treatments are needed. In type 1 diabetes, insulin production is absent, so insulin must be injected (see **Science Applied: How the Discovery of Insulin Made Diabetes Treatable**). Insulin cannot be taken orally because it is a protein that would be broken down in the GI tract, losing its ability to function. Type 2 diabetes can often be treated with oral medications that affect

SCIENCE APPLIED

How the Discovery of Insulin Made Diabetes Treatable

Diabetes was first described by Aretaeus of Cappadocia (in what is now Turkey) in the first century AD, but its cause was a mystery. Before the discovery of insulin, diabetes was a death sentence. The discovery of the connection between insulin and blood glucose, and the development of an injectable version of this hormone, allowed people with this once-deadly disease to live normal lives.

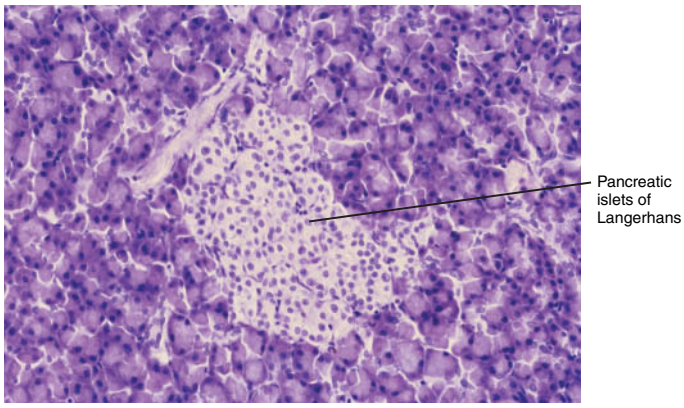
THE SCIENCE

In 1869, Paul Langerhans was studying the structure of the pancreas under a microscope when he noticed unusual clumps of tissue scattered throughout. These groups of cells were later identified as the insulin-producing tissue in the pancreas called the islets of Langerhans (see photo). In 1889, physician Oskar Minkowski removed the pancreas from a healthy dog to test its role in digestion. Several days later, Minkowski noticed a swarm of flies feeding on the dog's urine. On testing the urine, he found that it contained sugar. Without a pancreas, the dog was not producing insulin and was excreting glucose in his urine. This was the first connection between the pancreas and diabetes.

During the next two decades, research into diabetes and the pancreas continued. In 1921, Frederick Banting, intrigued by reading about the association between the pancreas and diabetes, became convinced that he could find the antidiabetic substance. Banting and two other Canadian researchers, John Macleod and Charles Best, first conducted experiments on dogs. The pancreas was removed from 10 dogs and these now-diabetic dogs were injected with an extract made from pancreatic islet cells. The pancreatic extract they had prepared was able to keep a dog alive by providing insulin.

Human studies of insulin began in January 1922 when Banting and colleagues used a pancreatic extract they called isletin to

Biophoto Associates/Photo Researchers, Inc.



These clumps of insulin-producing cells, called the islets of Langerhans, are destroyed in people with type 1 diabetes so no insulin can be produced.

insulin production and sensitivity, decrease glucose release by the liver, increase glucose excretion at the kidney, or slow carbohydrate digestion to keep blood glucose in the normal range. In some cases of type 2 diabetes, injected insulin is needed to achieve normal blood glucose levels.

Hypoglycemia

hypoglycemia A low blood glucose level, usually below 40 to 50 mg of glucose per 100 mL of blood.

Hypoglycemia is a condition in which blood sugar drops low enough to cause symptoms, including irritability, nervousness, sweating, shakiness, anxiety, rapid heartbeat, headache, hunger, weakness, and sometimes seizure and coma. It can occur in people with diabetes as a result of overmedication or an imbalance between insulin level and carbohydrate intake. People with diabetes must learn to recognize the symptoms of hypoglycemia and immediately treat them by consuming a source of quickly absorbed carbohydrate, such as juice or hard candy. Following this, a meal should be consumed within about 30 minutes to keep glucose in the healthy range.

In individuals without diabetes, hypoglycemia can result from abnormalities in the production of or response to insulin or other hormones involved in blood sugar regulation. There are two forms of hypoglycemia. The first, reactive hypoglycemia, occurs in response to the consumption of high-carbohydrate foods. The rise in blood glucose from the carbohydrate stimulates insulin release. However, too much insulin is secreted, resulting in a rapid fall in blood glucose to an abnormally low level. The treatment for reactive hypoglycemia is a diet that prevents rapid changes in blood glucose. Small, frequent meals low in simple carbohydrates and

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

treat 14-year-old Leonard Thompson, who was dying of diabetes; his blood sugar decreased. After further purifying the extract, Banting went from bed to bed treating children dying from diabetes.[34] One of the first American patients to receive insulin treatment was Elizabeth Gossett, the daughter of the governor of New York; with insulin treatment, she lived to the age of 73.[35] In 1923, Banting and Macleod were awarded the Nobel Prize for the discovery of insulin.[36]

THE APPLICATION

The first insulins used to treat humans were isolated and purified from the pancreatic islets of slaughtered animals, first dogs, then horses and pigs. They were used to treat diabetes for 50 years. For most patients they worked very well, but some developed allergies to the foreign proteins. In 1978, the biotechnology company Genentech produced the first synthetically manufactured insulin that could be mass produced. It was produced by inserting the gene for human insulin into bacterial DNA. This recombinant DNA was then transferred into either bacteria or yeast cells, which served as miniature "factories" to produce the human insulin. The genetically engineered human insulin did not cause the problems that animal insulin sometimes did.

Today in the United States, where close to 10% of the population has diabetes,[29] tens of thousands of Americans use insulin made by recombinant DNA technology. It is available in a variety of forms, some of which release quickly and some slowly. It can be delivered with a syringe, an insulin pen, or an insulin pump (see photo). Without this drug, thousands would die; with it, they can live healthy, productive lives.

© Mark Hatfield/iStockphoto

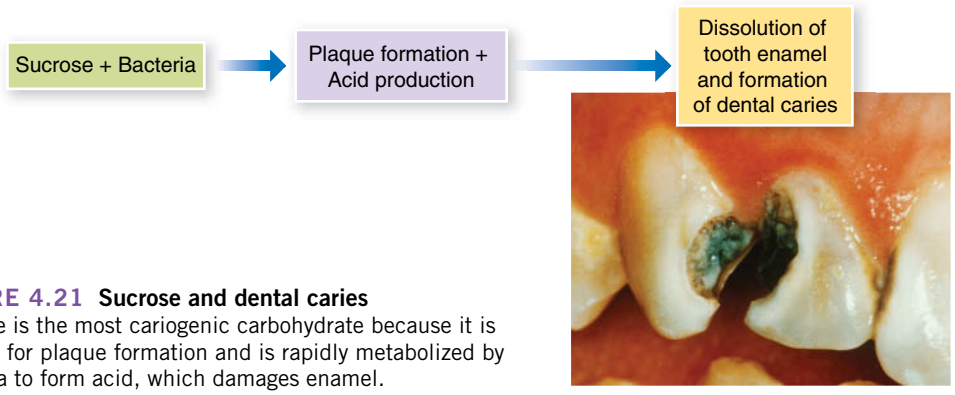
With the press of a button, people with diabetes today can pump in a dose of genetically engineered human insulin that matches the amount of carbohydrate consumed.

high in protein and fiber are recommended. A second form of hypoglycemia, fasting hypoglycemia, is not related to food intake. This disorder is often related to some underlying condition, such as excess alcohol consumption, hormonal deficiencies, or tumors. Treatment involves identifying and treating the underlying disease.

Dental Caries

The most well-documented health problem associated with a diet high in carbohydrates is **dental caries**, or tooth cavities. It is one of the most common childhood diseases in the United States; 92% of adults 20 to 64 years of age have had caries in their permanent teeth.[37] Cavities are caused when bacteria that live in the mouth form colonies, known as plaque, on the tooth surface. If the plaque is not brushed, flossed, or scraped away, the bacteria metabolize carbohydrate from the food we eat, producing acid. The acid can then dissolve the enamel and underlying structure of the teeth, forming cavities. Sucrose is considered the most cariogenic carbohydrate because, in addition to being metabolized to acid by oral bacteria, it is needed for the synthesis of materials that help bacteria stick to the teeth and form plaque (Figure 4.21).[38] Once plaque forms, simple carbohydrates are the most rapidly used food source for bacteria and therefore easily produce tooth-damaging acids, but starchy foods that stick to the teeth can also promote tooth decay. Foods such as gummy candies, cereals, crackers, cookies, and raisins and other sticky dried fruits tend to remain on the teeth longer, providing a continuous supply of nutrients

dental caries The decay and deterioration of teeth caused by acid produced when bacteria on the teeth metabolize carbohydrate.



Biophoto Associates/Photo Researchers, Inc.

FIGURE 4.21 Sucrose and dental caries
Sucrose is the most cariogenic carbohydrate because it is needed for plaque formation and is rapidly metabolized by bacteria to form acid, which damages enamel.

to decay-causing bacteria. Other foods, such as chocolate, ice cream, and bananas, are rapidly washed away from the teeth and therefore are less likely to promote cavities. Frequent snacking, sucking on hard candy, or slowly sipping soda can also increase the risk of cavities by providing a continuous food supply for the bacteria. Limiting sugar intake can help prevent dental caries, but other dietary factors and proper dental hygiene are important even if the diet is low in sugar. Dairy products, sugarless gums (sweetened with sugar alcohols), and fluoride reduce caries formation. Brushing teeth after eating reduces cavity risk no matter what food is consumed.

Carbohydrates and Weight Management

The popularity of low-carbohydrate diets for weight loss has given carbohydrates a reputation for being fattening. Carbohydrates in and of themselves are not "fattening." They provide 4 kcal/g compared with 9 kcal/g provided by fat (Figure 4.22). This is not to say that carbohydrate consumed in excess of energy needs will not add pounds. Any energy source consumed in excess of requirements can cause weight gain. Carbohydrates are no more fattening than any other energy source, but the amount and type of carbohydrate can affect how easily body weight is managed.

Danielle Loiselle/iStockphoto

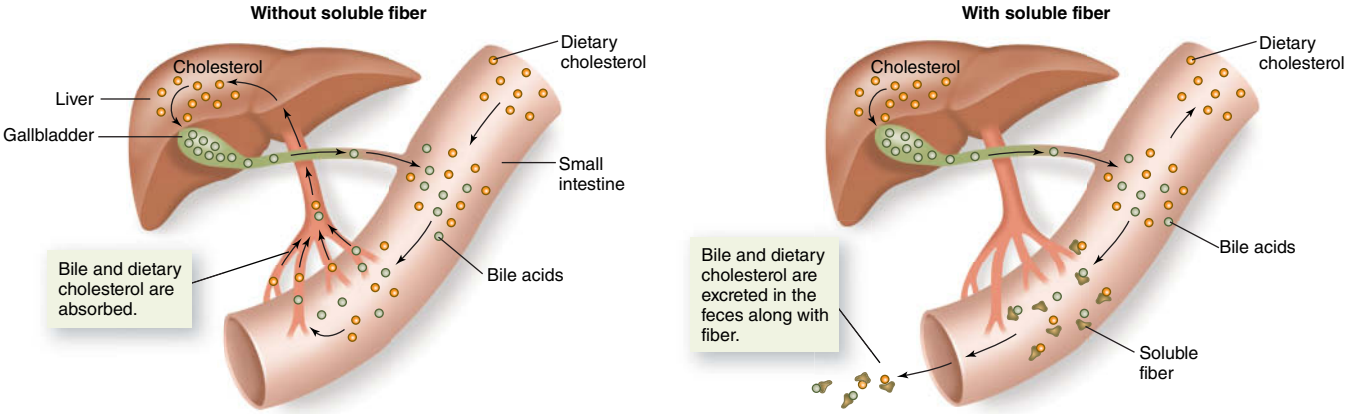
FIGURE 4.22
Carbohydrates and calorie intake
It is the fat we add to high-carbohydrate foods that increases their calorie tally. A medium-size baked potato provides about 160 kcal. Adding a tablespoon of butter brings the total to 260 kcal. A plate of plain pasta has about 200 kcal, but with a high-fat sauce, the kilocalories rise to 300; add sausage and the meal is now 450 kcal.

Refined versus Unrefined Carbohydrates and Weight Management High intakes of added sugars, especially sugar-sweetened beverages, increase the risk of gaining weight and becoming overweight or obese.[10] In contrast, diets high in fiber and whole grains are associated with lower body weight and prevention of weight gain.[39,40] This may occur because high fiber intake increases the sense of fullness by adding bulk and slowing digestion and absorption so one feels satisfied with less food. High-fiber diets also tend to be lower in fat and energy density and are associated with other beneficial lifestyle factors such as better exercise habits.[16] Diets high in unrefined foods have glycemic effects similar to diets low in carbohydrate and high in protein.[41] They cause a smaller rise in insulin than diets high in refined carbohydrates.

Why Low-Carbohydrate Diets Promote Weight Loss The rationale behind consuming a low-carbohydrate diet for weight loss is that foods high in carbohydrate stimulate the release of insulin, which is a hormone that promotes energy storage. It is suggested that the more insulin you release, the more fat you will store. Refined carbohydrates cause the greatest glycemic response and subsequent rise in insulin. They are therefore hypothesized to shift metabolism toward fat storage. In contrast, diets low in carbohydrate cause less of a glycemic response and less insulin release, which is suggested to promote fat loss.[41]

Weight loss while consuming a very low-carbohydrate diet may be aided by factors that affect energy intake and expenditure. Ketones, which accumulate when carbohydrate intake is limited, help suppress appetite and the high-protein content of these diets is satiating, so both help the dieter eat less. Low-carbohydrate, high-protein diets have also been found to cause less of a drop in energy expenditure than low-fat diets.[10] The weight loss on these diets, as with any weight-loss diet, is caused by a reduction in energy intake relative to expenditure. Which approach to weight loss is most effective depends on the individual (see Chapter 6, *Debate: The Highs and Lows of High-Protein Diets*).[41] Weight loss can be maintained only by continuing the lifestyle changes that led to the weight loss.

FIGURE 4.23 Soluble fiber reduces cholesterol and bile acid absorption



A. When the diet is low in soluble fiber, dietary cholesterol and bile acids, which are made from cholesterol, are absorbed into the blood and transported to the liver, where they are reused.

B. When soluble fiber is present in the digestive tract, the fiber binds cholesterol and bile acids so that they are excreted rather than absorbed. This helps reduce the amount of cholesterol in the body.

Carbohydrates and Heart Disease

The impact of carbohydrates on heart disease risk depends on the type of carbohydrate. There is evidence that diets with excess calories from sucrose or high-fructose corn syrup can raise blood lipid levels and thereby increase the risk of heart disease,[42] whereas diets high in whole grains and fiber have been found to reduce the risk of heart disease.[23,43] In addition to fiber, whole grains provide omega-3 fatty acids, vitamins, minerals, antioxidants, and other phytochemicals that may be protective against heart disease (see Chapter 5).

One of the ways that fiber may reduce the risk of heart disease is by lowering blood cholesterol levels. Soluble fiber binds cholesterol and bile acids, which are made from cholesterol, in the digestive tract.[44] Normally, bile acids secreted into the GI tract are absorbed and reused. When bound to fiber, they are excreted in the feces rather than being absorbed (Figure 4.23). The liver must then use cholesterol from the blood to synthesize new bile acids. This provides a mechanism for eliminating cholesterol from the body and reducing blood cholesterol levels. Soluble fibers from legumes, oats, guar gum, pectin, flaxseed, and psyllium (a grain used in bulk-forming laxatives such as Metamucil) are effective at reducing cholesterol, but insoluble fibers such as wheat bran or cellulose are not.[45] Fermentable fiber may also help lower blood cholesterol because some of the short-chain fatty acids produced by bacterial breakdown of the fiber may inhibit cholesterol synthesis in the liver.[16]

Because of the beneficial effects of fiber on heart disease risk, the FDA permits health claims on food products containing soluble fiber and fiber in general. Such claims state that these products may reduce the risk of coronary heart disease. In addition to lowering blood cholesterol levels, diets high in whole grains and other unrefined carbohydrates help lower blood pressure, normalize blood glucose levels, prevent obesity, and affect a number of other parameters, all of which help reduce the risk of heart disease.[43,45]

Fiber and Bowel Health

Fiber adds bulk and absorbs water in the gastrointestinal tract, making the feces larger and softer and reducing the pressure needed for defecation. This helps reduce the incidence of constipation and **hemorrhoids**, the swelling of veins in the rectal or anal area. It also lessens symptoms associated with **diverticulosis**, a condition in which outpouchings called **diverticula** (the singular is *diverticulum*) form in the wall of the colon (Figure 4.24).[46] Fecal matter may occasionally accumulate in these outpouchings, causing irritation, pain, inflammation, and infection, a condition known as **diverticulitis**. Treatment of diverticulitis usually includes antibiotics to reduce bacterial growth and a temporary decrease in fiber intake to prevent irritation of the inflamed tissues. Once the inflammation is resolved, however, a high-fiber intake is recommended to increase fecal bulk, decrease transit time, ease stool elimination, and reduce future attacks of diverticulitis.[47]

hemorrhoids Swollen veins in the anal or rectal area.

diverticulosis A condition in which pouches called **diverticula** protrude from the wall of the large intestine. When these become inflamed, the condition is called **diverticulitis**.

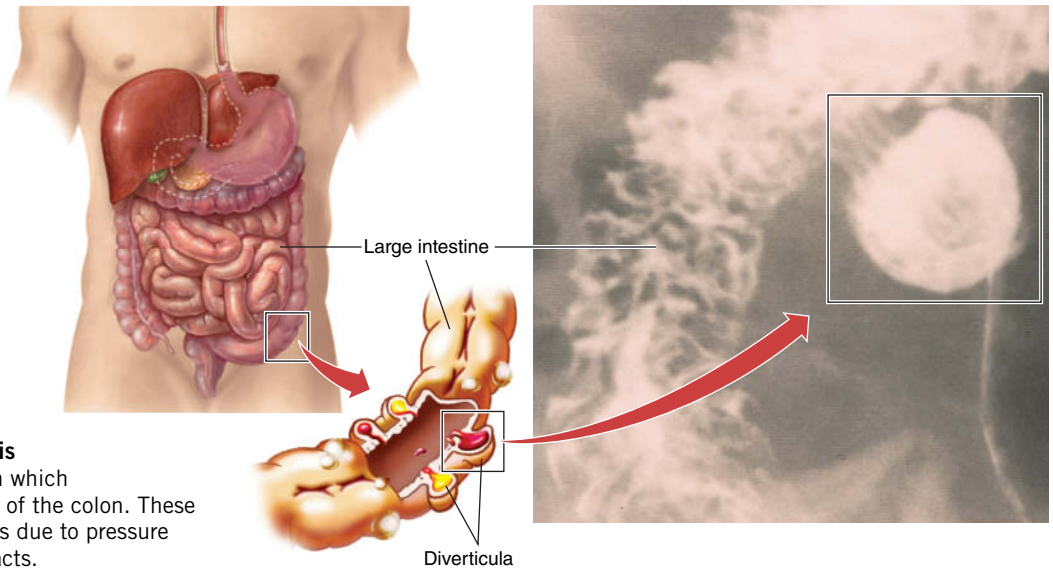


FIGURE 4.24 Diverticulosis
Diverticulosis is a condition in which outpouchings form in the wall of the colon. These diverticula form at weak points due to pressure exerted when the colon contracts.

Although fiber helps soften stools and prevent constipation, if fiber is consumed without sufficient fluid, it can also cause constipation. The more fiber there is in a diet, the more water is needed to keep the stool soft. When too little fluid is consumed, the stool becomes hard and difficult to eliminate. In severe cases when fiber intake is excessive and fluid intake is low, intestinal blockage can occur.

Fiber and Colon Cancer

Cancer is a disease that affects the way cells behave. Different cancers originate in different parts of the body and have different causes and effects. The type of cancer depends on the type of cell that is originally affected—for example, lung, breast, or colon—and on how the genetic material has been altered. Some people are more susceptible to cancer due to a genetic predisposition, but the development of most cancers is also influenced by environmental **carcinogens** from the diet, tobacco smoke, or air pollution. In the case of colon cancer, substances consumed in the diet or produced in the GI tract that come in contact with mucosal cells may contribute to cancer development.

carcinogens Cancer-causing substances.

mutations Changes in DNA caused by chemical or physical agents.

malignancy A mass of cells showing uncontrolled growth, a tendency to invade and damage surrounding tissues, and an ability to seed daughter growths to sites remote from the original growth.

How Cancer Cells Differ from Normal Cells Cells become cancerous as a result of **mutations** in their genetic material that allow them to reproduce without restraint and grow in abnormal locations. Normal body cells reproduce only to replace lost cells or to accommodate normal growth, but cancer cells divide continuously, forming enlarged cell masses known as *tumors*. Further mutations result in a mass of cells that can invade and colonize areas reserved for other cells, referred to as a **malignancy** (Figure 4.25). The cancer cells eventually crowd out the normal cells, robbing them of nourishment and preventing them from functioning properly. Some

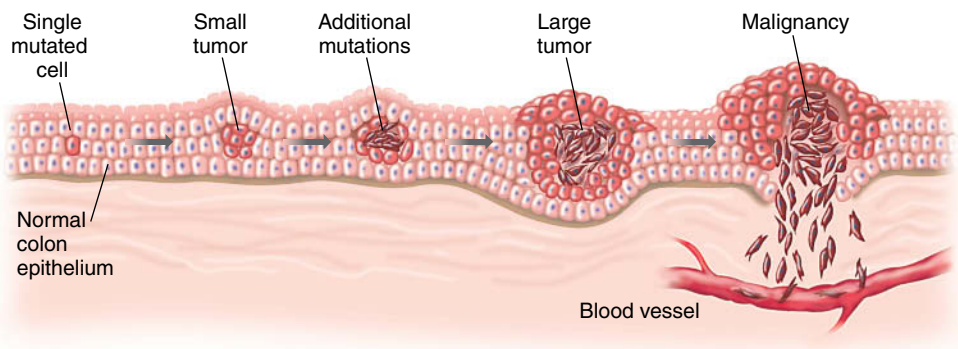


FIGURE 4.25 Development of colon cancer
Colon cancer, like other cancers, progresses from a single mutated cell to a tumor to a malignancy.

carcinogens act by damaging DNA and inducing mutations. These are usually referred to as *tumor initiators*, since the induction of mutations in key genes is thought to be the initiating event in cancer development. Other carcinogens contribute to cancer development by stimulating cells to divide. Such compounds are referred to as *tumor promoters*, since the increased cell division they induce enlarges the population of mutated cells, which is necessary for cancer to progress.

Why Fiber May Protect against Colon Cancer Epidemiological studies have found that the incidence of colon cancer is lower in populations consuming diets high in fiber and whole grains.[48] Several hypotheses have been suggested to explain how fiber might affect the development of colon cancer. One is related to its ability to decrease contact between the mucosal cells of the large intestine and the fecal contents, which may contain tumor initiators or tumor promoters. Fiber decreases contact by increasing fecal bulk, diluting the colon contents, and speeding transit.[49] Another hypothesis relates to the effect of fiber on the intestinal microbiota and the short-chain fatty acids it produces. These fatty acids directly support the health of colon cells and can inhibit the development of colon cancer by reducing inflammation and inhibiting the growth and migration of cancer cells.[49]

Intervention studies have not supported the epidemiological observations of a connection between fiber intake and colon cancer.[23] A number of reasons have been suggested for this discrepancy—the interventions were not long enough, the fiber dose was not high enough, the type of cancer monitored was not appropriate, or the fiber itself is not really protective but rather some other component in the diet of the low-cancer populations may have a protective effect. Despite mixed evidence that diets high in fiber protect against colon cancer, a dietary pattern that is high in fiber is still recommended to reduce the risk of chronic disease.[14,22]

4.6 Meeting Recommendations for Carbohydrate Intake

LEARNING OBJECTIVES

- List recommendations for total carbohydrate, added sugars, and fiber intake.
- Choose unrefined sources of carbohydrate from each food group of MyPlate.
- Use food labels to choose foods that provide healthy carbohydrates.
- Discuss the role of alternative sweeteners in weight management.

Recommendations for amounts and types of carbohydrate that promote health and prevent disease are made by the Dietary Reference Intakes (DRIs) and the Dietary Guidelines.[14,18] Following MyPlate and using the information on food labels can help translate these recommendations into appropriate food choices and overall healthy diets.

Carbohydrate Recommendations

A small amount of carbohydrate is needed to fuel the brain. Additional carbohydrate provides an important source of energy in the diet, and adequate fiber offers many health benefits. Therefore the DRIs make several kinds of recommendations for carbohydrate intake: Recommended Dietary Allowance (RDA) and an Acceptable Macronutrient Distribution Range (AMDR) for total carbohydrate intake and an Adequate Intake (AI) for fiber. Because no specific toxicity is associated with high intakes of carbohydrate in general or of different types of carbohydrates, no Tolerable Upper Intake Level (UL) has been established for total carbohydrate, added sugars, or fiber.

How Much Total Carbohydrate? The RDA for carbohydrate for adults and children has been set at 130 g/day based on the average minimum amount of glucose used by the brain.[18] In a diet that meets energy needs, this amount will provide adequate glucose and prevent ketosis. This amount of carbohydrate provides only 520 kcal; that's about 25% of the energy in a 2000-kcal diet. It is equivalent to the amount in a breakfast of a cup of juice, two slices of toast

TABLE 4.1 Calculating Percentage of Energy from Carbohydrate

Determine

- The total energy (kcal) intake for the day
- The grams of carbohydrate in the day's diet

Calculate energy from carbohydrate

- Carbohydrate provides 4 kcal/g
- Multiply grams of carbohydrate by 4 kcal/g

$$\text{Energy (kcal) from carbohydrate} = \text{grams carbohydrate} \times 4 \text{ kcal/g carbohydrate}$$

Calculate percentage of energy from carbohydrate

Divide energy from carbohydrate by total energy and multiply by 100 to express as a percentage

$$\text{Percentage of energy from carbohydrate} = \frac{\text{kcal from carbohydrate}}{\text{Total kcal}} \times 100$$

For example:

A diet contains 2500 kcal and 350 g of carbohydrate

$$350 \text{ g of carbohydrate} \times 4 \text{ kcal/g} = 1400 \text{ kcal of carbohydrate}$$

$$\frac{1400 \text{ kcal of carbohydrate}}{2500 \text{ kcal}} \times 100 = 56\% \text{ of energy (kcal) from carbohydrate}$$

with jam, and a bowl of cereal with half a banana and milk. Most people consume well in excess of this amount over the course of a day. Additional carbohydrate provides an important source of energy in the diet, and carbohydrate-containing foods can add vitamins, minerals, fiber, and phytochemicals. A diet that includes only 130 g of carbohydrate and meets calorie needs would be very high in protein and fat.

The AMDR for carbohydrate intake for a healthy diet has been set at 45 to 65% of energy (225 to 325 g in a 2000-kcal diet). Choosing a diet in this range will allow you to meet your energy needs without consuming excessive amounts of protein or fat. The percentage of energy from carbohydrate in your diet can be calculated by using the equations shown in Table 4.1. This same calculation can be used to determine the percentage of energy as carbohydrate in individual foods. The amount of carbohydrate in a food or in a diet can be estimated from the Choice (Exchange) Lists (Table 4.2) or determined using values from food labels, diet-analysis

TABLE 4.2 Using Choice (Exchange) Lists to Estimate Carbohydrate Content

Food groups/lists	Serving size	Carbohydrates (g)
Carbohydrate group		
Starch	⅓ cup pasta; ½ cup potatoes; 1 slice bread	15
Fruit	1 small apple, peach, pear; ½ banana; ½ cup canned fruit (in juice)	15
Milk	1 cup milk or yogurt	
Nonfat		12
Low-fat		12
Reduced-fat		12
Whole		12
Other carbohydrates	Serving sizes vary	15
Vegetables	½ cup cooked vegetables, 1 cup raw	5
Meat/meat substitute group	1 oz meat or cheese	
Very lean		0
Lean		0
Medium-fat		0
High-fat		0
Fat group	1 tsp butter, margarine, or oil; 1 T salad dressing	0

TABLE 4.3 Comparing Fiber Content

Food group/serving	High fiber (4 g or more)	Medium fiber (More than 1 g, but less than 4 g)	Low fiber (Less than 1 g)
Grains			
Breads (1 slice)	—	Pumpernickel, whole wheat, rye	White bread, bagel (½), tortilla, roll (½), English muffin (½), graham crackers (2)
Cereals (½ cup)	All Bran, Fiber One, Raisin Bran, Oat Bran	Shredded Wheat, Cheerios, oatmeal	Rice Krispies, Special K, Cream of Wheat
Rice and pasta (½ cup)	—	Whole-wheat pasta, brown rice, barley	White pasta, white rice
Fruits			
Fruits (1 medium or ½ cup)	Berries, prunes, figs	Apple, pear, apricot, banana, orange, raisins, plum, mango, prunes	Melon, grapes, juice
Vegetables			
Vegetables (½ cup)	Peas, okra, spinach, turnips, sweet potatoes	Asparagus, broccoli, Brussels sprouts, green beans, onion, green pepper, kale, carrots	Mushrooms, cucumbers, iceberg lettuce, potatoes without skin
Dry beans (½ cup)	Pinto beans, red kidney beans, black-eyed peas, lentils	—	—
Nuts and seeds (¼ cup)	Flaxseeds	Almonds, peanuts, sesame seeds, sunflower seeds	—

computer programs, or food composition tables (see iProfile or online *Nutrient Composition of Foods* supplement).

What Types of Carbohydrates Are Recommended? A healthy diet is high in unrefined carbohydrates; refined carbohydrates and added sugars should be limited.

Unrefined carbohydrates are good sources of fiber. The AI for fiber is based on the amount of fiber needed to reduce heart disease risk.[18] For young adult men, it is 38 g/day, and for young adult women, it is 25 g/day. The AI for fiber depends on energy intake so it is lower for children and older adults, who require fewer calories (see inside cover). Eating a bowl of Raisin Bran with a half-cup of strawberries for breakfast, a sandwich on whole-wheat bread with lettuce and tomatoes and an apple for lunch, eggplant parmesan for dinner, and popcorn for a snack will provide about 25 g of fiber. Table 4.3 compares the fiber content of a variety of grains, fruits, vegetables, and other plant foods.

There is no RDA or Daily Value for added sugars, but the Dietary Guidelines recommend reducing the consumption of added sugars to no more than 10% of calories.[14] Similar recommendations are made by the American Heart Association and the World Health Organization.[50,51] For a 2000-kcal diet, that's no more than 200 kcal/day, or about 12 teaspoons of sugar. Reducing added sugars reduces calorie intake without reducing essential nutrients.

Translating Recommendations into Healthy Diets

A healthy diet is high in complex carbohydrates from whole grains, legumes, fruits, and vegetables and unrefined simple carbohydrates from foods such as fresh fruit and low-fat dairy products. This diet is high in fiber, micronutrients, and phytochemicals. Unfortunately, the typical American diet is lower in whole grains, fruits, vegetables, and fiber and higher in added sugars than is recommended.

Using MyPlate to Make Healthy Choices Following the recommendations of MyPlate promotes a dietary pattern that is high in whole grains, fruits and vegetables, and low-fat dairy products while limiting foods high in refined grains and added sugars, such as soft drinks and other sweetened beverages, sweet bakery products, and candy (Figure 4.26).

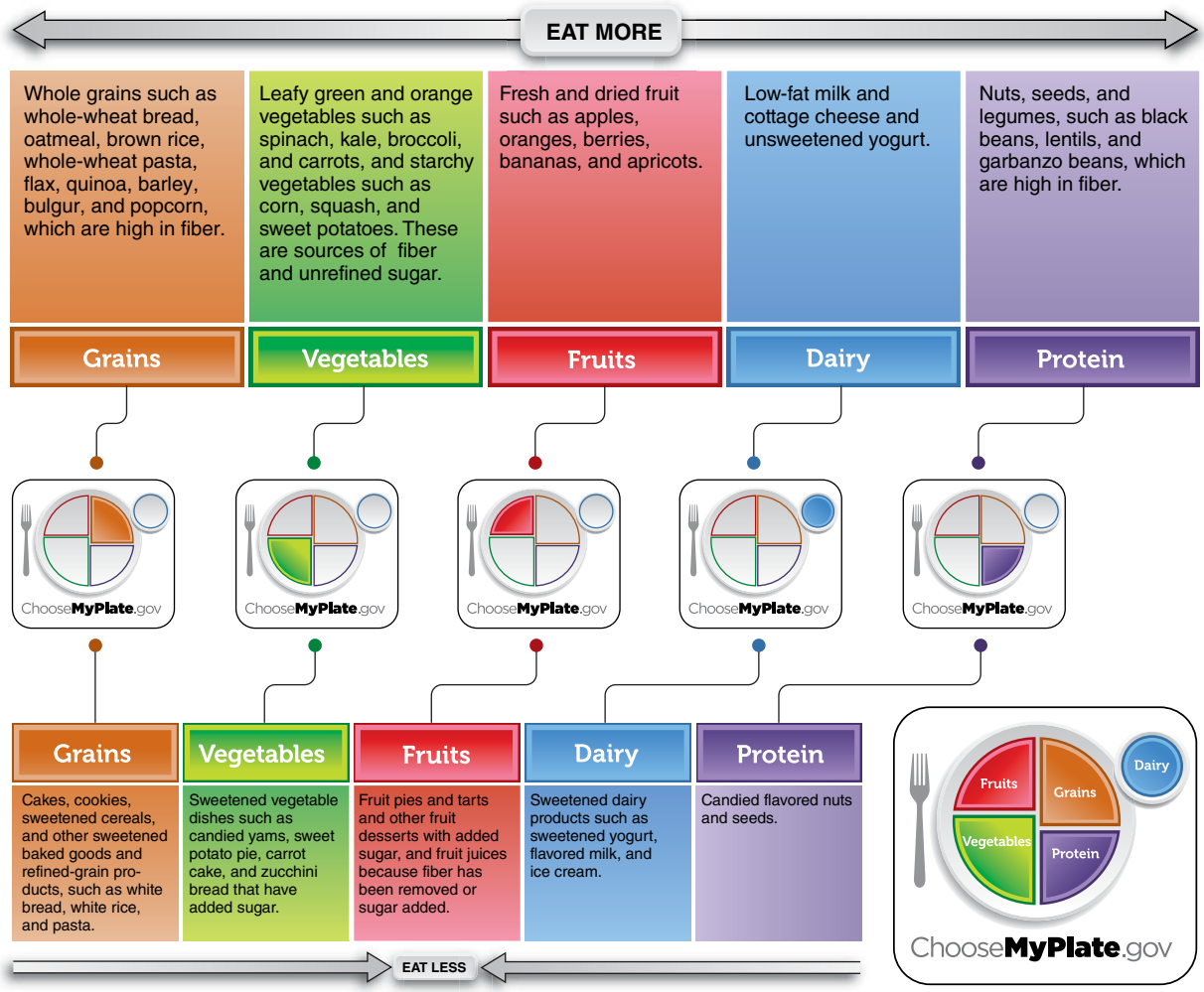


FIGURE 4.26 Healthy MyPlate carbohydrate choices
The healthiest carbohydrate choices are whole grains, legumes, and fresh fruits and vegetables, which are low in added sugar and often are good sources of fiber. Foods containing refined carbohydrates should be limited because they are typically low in fiber and contain added sugars, which add empty calories.

Eat More Whole Grains, Fruits, and Vegetables To encourage the consumption of healthy sources of carbohydrates, MyPlate recommends that you choose half of your grains from whole sources or eat at least three servings of whole grains per day. Whole grains are good sources of fiber as well as micronutrients and phytochemicals. Fruits and vegetables are also excellent unrefined food sources of both complex and simple carbohydrates. For a 2000-kcal diet, MyPlate recommends 2 cups of fruit and 2½ cups of vegetables. To maximize fiber intake, most fruit choices should be whole fruits rather than juices. An apple provides about 80 to 90 kcal and 2.7 g of fiber, whereas a cup of apple juice provides the same amount of energy but almost no fiber (0.2 g). Choosing legumes as part of the protein or vegetables servings will increase fiber intake—one-half cup of cooked black beans has about 7 g of fiber.

Limit Added Sugars Americans consume about 13% of their calories as added sugar; the numbers for children are even higher—about 15 to 17% of calories.[52,53] Sugar-sweetened beverages such as carbonated soft drinks, energy drinks, sports drinks, and sugar-sweetened fruit drinks contribute about a third of calories consumed as added sugars in adults and 41% in children and teens. Foods such as candy, cakes, cookies, pies, dairy desserts, and thousands of other sweetened processed products contribute the rest.[52,53] The greater your consumption of foods high in added sugars, the harder it is to meet your nutrient needs without gaining weight. People who eat foods and beverages high in added sugars tend to consume more calories and fewer

Ken Karp

Food	Amount of added sugar (tsp)	Energy from added sugar (kcal)
Cookies, 2 medium chocolate chip	3	48
Frosted cornflakes, 1 oz	3	48
Cake, frosted, 2 oz	6	96
Pie, fruit, 2-crust, ⅛ of 9"	6	96
Fruit, canned in heavy syrup, 1 cup	4	64
Low-fat fruit yogurt, 1 cup	7	112
Ice cream, vanilla, 1 cup	3	48
Chocolate bar, 1 oz	5	80
Fruit drink, 12 oz	12	192
Cola, not diet, 20-oz bottle	15	240

FIGURE 4.27 How much added sugar do you eat?
These foods all contribute to the added sugar content of your diet. Assuming you need 2000 kcal/day, which combinations of foods listed here could you consume without exceeding the recommendation for added sugars?

micronutrients. To keep added sugars to no more than 10% of calories, consumption of sugar-sweetened beverages, cereals, snacks, and desserts must be kept to a minimum (Figure 4.27).

Putting It All Together To meet the recommendations for a healthy diet, refined carbohydrates should be replaced with unrefined sources of simple and complex carbohydrates (see **How to Choose: Healthy Carbohydrates**). For example, choosing a stir-fry meal of a few ounces of lean beef and plenty of vegetables on brown rice can provide the same calories but more fiber than a dinner of steak, white rice, and a small salad with dressing. To limit added sugars, foods high in added sugar should be replaced with natural sources of sugar such as fruits and unsweetened dairy products (see **Critical Thinking: Becoming Less Refined**).[14] If instead of a 20-oz bottle of soda you have an 8-oz glass of low-fat milk, you will consume 140 fewer kcal and no added sugar, as well as getting plenty of high-quality protein, calcium, vitamin D, and other micronutrients.

HOW TO CHOOSE Healthy Carbohydrates

Make half your grains whole

- Have your sandwich on whole-wheat, oat bran, rye, or pumpernickel bread.
- Switch to whole-wheat pasta and brown rice.
- Fill your cereal bowl with plain oatmeal and add a few raisins for sweetness.
- Check the ingredient list for the words "whole" or "whole grain" before the grain ingredient's name.

Increase your fruits and veggies

- Don't forget beans. Kidney beans, chickpeas, black beans, and others have more fiber than any other vegetables.
- Add berries, bananas, or dried fruit to cereal and desserts.
- Pile veggies, such as lettuce, tomatoes, cucumbers, avocados, and peppers, on your sandwich.
- Have more than one vegetable at dinner, and try a new fruit.

Limit added sugars

- Switch from sugar-sweetened soft drinks to water or low-fat milk.
- Use one-quarter less sugar in your recipe next time you bake.
- Snack on a piece of fruit instead of a candy bar.
- Check the ingredient list on breakfast cereals to find ones that have no added sugar.

CRITICAL THINKING

Becoming Less Refined

© Sharo/iStockphoto

Emma thinks that a good diet is important. She is concerned that she eats too much added sugar and not enough fiber. She records her food intake for a day and calculates its nutrient content.

DIET ANALYSIS

Emma's typical diet provides 2340 kcal and 350 g of carbohydrate. The amounts of fiber and sugars in each food are shown in the table.

Calculate the percentage of calories from carbohydrate in Emma's diet. Does it meet the AMDR?

FOOD	SERVING	FIBER (g)	SUGARS (g)
Breakfast			
White bread	2 slices	1.2	2
with jelly	1 T	0.1	6
and margarine	1 tsp	0	0
Fruit punch	8 fl oz	0	22
Lunch			
Macaroni and cheese	1 cup	1.4	8
Milk	1 cup	0	12
Apple	1 medium	3.7	18
Snack			
Soda	20 oz	0	63
3 Musketeers bar	1 regular	1	34
Dinner			
Roast beef	3 oz	0	0
Flour tortillas	1, 8-inch size	1.4	1
Pinto beans	1 cup	10	1
Snack			
Ice cream	⅔ cup	0.8	17
with cherry syrup	2 T	0	16
Total		19.6	200

Based on the information in the table, does her diet meet fiber recommendations?

CRITICAL THINKING QUESTIONS

- **Find three foods in Emma's diet that are low in fiber and high in sugar and suggest an alternative for each that will provide less added refined sugar and/or more fiber.**
- **Is a diet that meets the AMDR for carbohydrate necessarily a healthy diet?**

iProfile Use iProfile to see how much fiber you would add to your diet if you made all your bread whole grain.

Using Food Labels to Make Healthy Choices Food labels can help in choosing the right mix of carbohydrates. The Nutrition Facts panel helps consumers find foods that are good sources of fiber and low in sugars (Figure 4.28). The ingredient list helps identify whole-grain products and the sources of added sugars (see **Off the Label: What Does the Ingredient List Tell You about Carbohydrates?**).

Many food labels indicate that the product is made from whole grains or include nutrient content claims such as "high fiber" or "excellent source of fiber," which can help you find high-fiber products (see Figure 4.28). If you are looking for low-carbohydrate products, be aware

Raisin Bran®

Nutrition Facts

Serving Size 1 Cup (59g)

Amount Per Serving	Cereal	with 1/2 cup skim milk
Calories	190	230
Calories from Fat	10	10
		% Daily Value**
Total Fat 1g*	**2%**	**2%**
Saturated Fat 0g	**0%**	**0%**
Trans Fat 0g		
Polyunsaturated Fat 0g		
Monounsaturated Fat 0g		
Cholesterol 0mg	**0%**	**0%**
Sodium 210mg	**9%**	**12%**
Potassium 310mg	**9%**	**15%**
Total Carbohydrate 46g	**15%**	**17%**
Dietary Fiber 7g	**28%**	**28%**
Sugars 18g		
Protein 5g		
Vitamin A	10%	15%
Vitamin C	0%	0%
Calcium	2%	15%
Iron	25%	25%
Vitamin D	10%	25%
Thiamin	25%	30%
Riboflavin	25%	35%
Niacin	25%	25%
Vitamin B_6	25%	25%
Folic Acid	25%	25%
Vitamin B_{12}	25%	35%
Phosphorus	20%	30%
Magnesium	20%	25%
Zinc	10%	15%

* Amount in cereal. One-half cup of skim milk contributes an additional 40 calories, 65mg sodium, 6g total carbohydrates (6g sugars), and 4g protein.

** Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat. Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Potassium		3,500mg	3,500mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Total carbohydrate content is listed in grams and as a percentage of the Daily Value.

The total amount of fiber in the product is listed in grams and as a percentage of the Daily Value. The amounts of soluble and insoluble fiber may be listed if manufacturers choose to include them but are not required.

The number of grams of sugars listed includes the total amounts of mono- and disaccharides but does not distinguish between added sugar and the sugar that occurs naturally in food. Proposed changes to the Nutrition Facts include putting grams of added sugars as a separate line below Sugars.

The Daily Value for total carbohydrate is calculated as 60% of the energy. For a 2000-kcal diet, this represents 300 g of carbohydrate ([2000 kcal x 0.6]/4 kcal/g of carbohydrate = 300 g).

The Daily Value for fiber is 25 g in a 2000-kcal diet.

Sugar and Fiber Descriptors on Food Labels

Sugar-free	Product contains no amount, or a trivial amount, of sugars (less than 0.5 g per serving). Synonyms for "free" include "without," "no," and "zero."
Reduced sugar	Nutritionally altered product contains 25% less sugar than the regular or reference product.
Less sugar	Whether altered or not, a food contains 25% less sugar than the reference food. "Fewer" may be used as a synonym for "less."
No added sugars or without added sugars	No sugar or sugar-containing ingredient is added during processing.
High fiber	Food contains 20% or more of the Daily Value for fiber per serving. Synonyms for "high" include "rich in" and "excellent source of."
Good source of fiber	Food contains 10 to 19% of the Daily Value for fiber per serving. Synonyms for "good source of" include "contains" and "provides."
More fiber	Food contains 10% or more of the Daily Value for fiber per serving than an appropriate reference food. Synonyms for "more" include "added" (or "fortified" and "enriched"),"extra," or "plus."

© Roel Smart/iStockphoto

FIGURE 4.28 Carbohydrates on food labels
The Nutrition Facts panel lists the grams of total carbohydrate, fiber, and sugars in foods. This label from Raisin Bran tells you that it is high in fiber, but also high in sugars. The table defines descriptors used to highlight the sugar and fiber content of foods.

that the terms "low carbohydrate" and "low carb" have not been defined by the Food and Drug Administration (FDA), so at the moment, the definition is up to the manufacturer. Some products may also advertise the number of grams of "net carbs" they provide. Again, there is no official definition of net carbs, but usually this number is calculated by subtracting the grams of fiber, and sometimes other poorly absorbed carbohydrates, from the grams of total carbohydrate in the food.

Health claims can also help identify foods that are good sources of whole grains and fiber. Foods that are low in fat and contain at least 51% of their weight as whole grains can include the health claim that states, "Diets rich in whole-grain foods and other plant foods and low in total fat, saturated fat, and cholesterol may help reduce the risk of heart disease and certain cancers."[54] Fiber-containing grain products, fruits, and vegetables that contain at least 2.5 g of fiber per serving and are low in fat may claim to reduce the risk of cancer. Fruits, vegetables, and grain products

OFF THE LABEL

What Does the Ingredient List Tell You about Carbohydrates?

© iStockphoto

How can you tell whether your breakfast cereal is made with whole grains or whether the sugar in your canned peaches is added or natural? It turns out that much of the information you need to make healthy carbohydrate choices must be found in the ingredient list, rather than on the Nutrition Facts panel. The key to understanding the ingredient list is that ingredients are listed in order of their prominence by weight, so the closer to the front of the list an ingredient appears, the more of it there is in the food.

To see if your choice is a whole-grain product, look to see if the first ingredient is a whole grain. Whole wheat, whole oats, oatmeal, rolled oats, whole-grain corn, popcorn, brown rice, whole rye, whole-grain barley, wild rice, buckwheat, triticale, bulgur, cracked wheat, millet, quinoa, and sorghum are whole grains. Wheat flour is not. "Wheat" refers to the type of grain, not how refined it is. Products whose first ingredient is wheat flour, enriched flour, or degerminated cornmeal are not made predominantly from whole grains. Don't be fooled by healthy-sounding descriptors like "multi-grain" or "seven-grain." These simply mean the product contains more than one type of grain, not that these grains are necessarily whole grains. "Stone ground" refers to how the grain was processed, not whether the bran and germ are included; and terms like "bran" and

Lori Smolin

The first ingredient in this beard is whole-wheat flour and the third is wheat flour. Therefore, this is not a 100% whole-grain product. It advertises seven grains, but it is not clear whether all the grains are whole and many, such as triticale, barley, and millet, are towards the end of the list, so are present only in small amounts.

INGREDIENTS: WHOLE WHEAT FLOUR, WATER, UNBLEACHED ENRICHED WHEAT FLOUR [FLOUR, MALTED BARLEY FLOUR, REDUCED IRON, NIACIN, THIAMIN MONONITRATE (VITAMIN B1), RIBOFLAVIN (VITAMIN B2),FOLIC ACID], SUGAR, MOLASSES, CRACKED WHEAT, CELLULOSE FIBER, WHEAT GLUTEN, RYE, YEAST, SOYBEAN OIL, SALT, BROWN RICE, OATS, CALCIUM PROPRIONATE (PRESERVATIVE), MONOGLYCERIDES, GRAIN VINEGAR, TRITICALE, BARLEY, FLAXSEED, MILLET, DATEM, CALCIUM SULFATE, CITRIC ACID, SOY LECITHIN, NONFAT MILK, NUTS [WALNUTS AND/OR HAZELNUTS (FILBERTS) AND/OR ALMONDS], CALCIUM CARBONATE

Each slice of this bread contains 3 g of fiber. This fiber comes from the whole-wheat flour and the other whole grains as well as the added fiber (cellulose and flaxseed).

that are low in total fat, saturated fat, and cholesterol and that contain at least 0.6 g of soluble fiber per serving, and foods that contain at least 0.75 g of soluble fiber per serving from whole oats or psyllium husks, may claim to reduce the risk of heart disease (see online Appendix H).

The Role of Alternative Sweeteners

America's love of sweets and the bad press surrounding sugar have driven the technological development of an increasing number of alternative or artificial sweeteners. These sugar substitutes, which provide little or no energy, are added to a host of low-calorie and "light" foods such as yogurts, ice creams, and soft drinks. Although many sugar substitutes are technically not carbohydrates, they were developed to replace simple sugars added to food products or as an alternative for table sugar at home.

When alternative sweeteners are used to replace added sugars in the diet, they can help reduce the incidence of dental caries and manage blood sugar levels. The effect that these products have on body weight depends on whether the calories they spare are added back from other food sources. The majority of studies suggest that obesity rates are lower when artificially sweetened beverages replace sugar-sweetened beverages but their effectiveness in long-term weight management has not been proven.[14] There is no evidence that the use of artificial sweeteners

Lori Smolin

The yogurt label shown here lists sugar as the second ingredient and high-fructose corn syrup as the fourth. Together these two contribute much of the sugar in this food.

INGREDIENTS: CULTURED PASTEURIZED GRADE A REDUCED FAT MILK, SUGAR, NONFAT MILK, HIGH FRUCTOSE CORN SYRUP, STRAWBERRY PUREE, MODIFIED CORN STARCH, KOSHER GELATIN, TRICALCIUM PHOSPHATE, NATURAL FLAVOR, COLORED WITH CARMINE, VITAMIN A ACETATE, VITAMIN D_3

This yogurt contains 28 g of sugars per serving. This amount includes both the sugar found naturally in the strawberries and milk (about 12 g), plus the sugar added for more sweetness (about 16 g).

"oat" may refer to things added to the product, not whether the product is made predominantly from a whole grain. Don't forget to look at the rest of the ingredient list, too. The presence of whole grain is not the only criterion for a healthy choice. For example, Lucky Charms cereal is a whole grain, but marshmallows are the second ingredient, making it high in sugar as well.

The value listed for "Sugars" on the Nutrition Facts panel includes all sugars and doesn't differentiate between added and natural sugar. Proposed changes to the Nutrition Facts label would require that the added sugars be listed separately from total sugars. Until this change is made, checking the ingredient list is the only way to identify foods that are high in "added" sugar. The sweeteners in the ingredient list are those added as ingredients, not the sugar that is naturally present in the food. Foods that are high in added sugar will have a sweetener listed early in the ingredient list. If the first ingredient is sugar, then that product contains more sugar by weight than anything else. Remember, though, that the sum of the added sweeteners hiding farther down in the ingredient list may be considerable. Recognizing added sugars can also be a challenge. The only sweetener that can be called "sugar" on the ingredient list is sucrose; sucrose is found in brown, powdered, granulated, and raw sugar, and each form may be listed separately. Many other types of sugars are also added to foods. Dry sugars that are added include invert sugar, dextrose, glucose, maltose, lactose, and fructose. Corn syrup, honey, molasses, malt syrup, sugar syrup, fruit juice concentrates, and high-fructose corn syrup are added as syrups. Increasing your sugar vocabulary will help you keep track of the high-sugar foods in your diet.

causes higher body weight in adults.[14,55] Animal studies suggest that artificial sweeteners may stimulate appetite, leading to weight gain, but this hypothesis has not been supported by studies done in humans.[56] Weight gain seen in some studies of artificial sweetener users is more likely to be due to the fact that individuals at higher risk of obesity are more likely to use artificial sweeteners to try to control weight.

Even if replacing foods high in added sugars with foods sweetened with sugar substitutes cuts down on calories and decreases sugar intake, switching to alternative sweeteners will not necessarily make your diet healthier. Using alternative sweeteners will not increase the intake of whole grains or fresh fruits and vegetables—key components of a healthy diet. Foods that are high in added sugar tend to be nutrient poor. Replacing them with artificially sweetened alternatives does not necessarily increase the nutrient density of the diet or improve overall diet quality. However, these products can be part of a healthy diet when used in moderation as part of a diet that is based on whole grains, vegetables, and fruits.

Types of Nonnutritive Sweeteners Alternative sweeteners that provide no calories are often referred to as *nonnutritive sweeteners*. The main competitors in the nonnutritive sweetener market in the United States today are saccharin, aspartame, sucralose, acesulfame K (acesulfame potassium), and stevia (Table 4.4). These are used alone or in combination to sweeten a variety

TABLE 4.4 Nonnutritive Sweeteners Approved by the FDA

Sweetener	Brand names	What is it?	Acceptable daily intake (ADI)
Acesulfame K	Sunett, Sweet One, Swiss Sweet © Sara Wight	A heat-stable sweetener that is often used in combination with other sweeteners. It is 200 times sweeter than sucrose.	15 mg/kg of body weight/day. A 154-lb (70-kg) person could consume 2 gallons of beverages containing acesulfame K without exceeding the ADI.
Aspartame	Equal, NutraSweet, NatraTaste Andy Washnik	Made of two amino acids (phenylalanine and aspartic acid). Because it breaks down when heated, it is typically used in cold products or added after cooking. It is 160–220 times sweeter than sucrose.	50 mg/kg of body weight/day. One packet contains 37 mg of aspartame. To exceed the ADI, a 154-lb (70-kg) person would have to consume 95 packets or sixteen 12-oz aspartame-sweetened beverages. It must be limited in the diets of people with phenylketonuria (see Chapter 6).
Luo han guo extract, *Siraitia grosvenorii*, or Monk fruit extract	Purelo Lo Han sweetener, LoSweet, Fruit-Sweetness, Monk Fruit in the Raw Lori Smolin	150–300 times sweeter than sucrose. Given *generally recognized as safe* status (see Chapter 17) in 1997. May have an aftertaste at high levels. Intended as a tabletop sweetener and a component of other sweetener blends.	No ADI determined.
Neotame	No brand name. Neotame is not sold as a table sweetener.	Made from the same two amino acids as aspartame, but because the bond between them is harder to break than the bond in aspartame, it is heat stable and can be used in baked goods. It is also used in soft drinks, dairy products, and gum. It is 8000 times sweeter than sucrose.	18 mg/kg of body weight/day.
Saccharin	Sweet'N Low, SugarTwin, Necta Sweet Andy Washnik	The oldest of the nonnutritive sweeteners, developed in 1879. It was once considered a carcinogen but was taken off the government's list of cancer-causing substances in 2000. It is 300 times sweeter than sucrose and has a bitter aftertaste.	5 mg/kg of body weight/day. One packet contains 36 mg of saccharin. A 154-lb (70-kg) person would exceed the ADI by consuming 10 packets or about three 12-oz saccharin-sweetened beverages.
Stevia sweetener	Truvia, Pure Via © Sara Wight	A natural sweetener made from the leaf of the stevia plant. It is the newest sweetener on the market and is about 300 times sweeter than sucrose.	4 mg/kg of body weight/day (expressed as steviol). To exceed the ADI, a 154-lb (70-kg) person would have to consume more than 30 packets of a stevia sweetener or drink about six 12-oz cans of a stevia-sweetened soda.
Sucralose	Splenda Andy Washnik	Made from sucrose molecules that have been modified so that they cannot be digested or absorbed. It is heat stable, so it can be used in cooking. It is 600 times sweeter than sucrose.	5 mg/kg of body weight/day. One packet contains about 12 mg of sucralose. A 154-lb (70-kg) person could consume 29 packets without exceeding the ADI.

of foods. Cyclamate, a nonnutritive sweetener that was popular in the 1960s, was banned by the FDA in 1969 so is no longer available in the United States. It is still sold in Canada and some 50 other countries.

Nonnutritive sweeteners consumed in reasonable amounts are generally safe for healthy people.[56] Aspartame is a special concern for individuals who have a genetic disorder called *phenylketonuria (PKU)*. These individuals must restrict their intake of phenylalanine, one of the amino acids that make up aspartame, to prevent brain damage (see Chapter 6). The FDA has defined acceptable daily intakes (ADIs)—levels that should not be exceeded when using these products (see Table 4.4). The ADI is an estimate of the amount of the sweetener per kilogram of body weight that an individual can safely consume every day over a lifetime with minimal risk.

Sugar Alcohols

Sugar alcohols are another type of alternative sweetener. Also called polyols, sugar alcohols such as sorbitol, mannitol, lactitol, and xylitol are chemical derivatives of sugar that are not digested, absorbed, or metabolized to the same extent as monosaccharides and disaccharides and thus generally provide less energy than sucrose. Sorbitol provides 2.6 kcal/g, lactitol 2 kcal/g, and erythritol only 0.2 kcal/g. Because they are not monosaccharides or disaccharides, sugar alcohols can be used in products labeled "sugar free" or "no sugar added." If a product uses these descriptors, the grams of sugar alcohols in a serving must be listed in the Nutrition Facts portion of the food label under carbohydrates.

sugar alcohols
Sweeteners that are structurally related to sugars but provide less energy than monosaccharides and disaccharides because they are not well absorbed.

Products sweetened with sugar alcohols, such as chewing gums, candies, ice creams, and baked goods, may carry the health claim statement that they do not promote tooth decay. These products are less likely to promote tooth decay because the bacteria in the mouth cannot metabolize sugar alcohols as rapidly as sucrose. Consumption of large amounts of some sugar alcohols (more than 30 g/day) can cause gas, bloating, and diarrhea.

OUTCOME

When Shamara abandoned her low-carb diet in favor of the dietary pattern recommended by MyPlate, she was pleased to be able to eat many of her favorite foods again, but she still struggled to limit her added sugars. She now understands that the meats, vegetables, and fresh fruits she eats at dinner don't contain added sugars. The added sugar in her diet comes from the packaged cereals she eats for breakfast and the soda, snacks, and baked goods she eats between meals.

She has learned to identify added sugar on food labels and found a few snack choices that are high in whole grains and not in added sugar. Now she chooses one of these instead of a muffin or pastry when she stops at the coffee shop. To keep her sugar intake down, she has learned to avoid the desserts in the cafeteria and to drink water or milk rather than sweetened beverages. She has stocked her room with healthy snacks, such as fruit, baby carrots, and whole-grain crackers. She is happy that by cutting out the sugar and watching her portion sizes she has been able to slowly lose some weight without the drastic changes her low-carb diet had required. **Shamara's new diet is flavorful and varied, so she can more easily stick with it in the long term.**

SUMMARY

4.1 Carbohydrates in Our Food

- Some carbohydrates in our diets are from unrefined whole foods such as whole grains, fruits, and vegetables. Others are from refined grain products like white breads and baked goods, and added sugars such as those found in candies and soft drinks.
- Unrefined sources of carbohydrate contain a variety of nutrients and phytochemicals. Much of the fiber and vitamins and minerals is lost when the food is refined.
- Added refined sugars provide energy but few nutrients, so they reduce the nutrient density of the diet.

4.2 Types of Carbohydrates

- Carbohydrates are chemical compounds that contain carbon, hydrogen, and oxygen. Simple carbohydrates, also called sugars, include monosaccharides and disaccharides. They are found in foods such as table sugar, honey, milk, and fruit.
- Complex carbohydrates include oligosaccharides and larger polysaccharides. Glycogen is a polysaccharide found in animals, and starch and fiber are polysaccharides found in plants. Neither soluble nor insoluble fiber can be digested by human enzymes. Soluble fiber forms viscous solutions in water and is more readily broken down by bacteria in the large intestine than is insoluble fiber.

4.3 Carbohydrates in the Digestive Tract

- Sugars and starches consumed in food are broken down in the digestive tract to monosaccharides, which can be absorbed into the bloodstream.
- Lactose intolerance occurs when the enzyme lactase is not available in sufficient quantities to digest lactose. Undigested lactose passes into the colon where it draws in water and is metabolized by bacteria, producing gas and acids and causing symptoms that include bloating, diarrhea, and flatulence. Lactose intolerance is more common in some populations than others.
- Fiber includes lignin, some oligosaccharides, resistant starch, and other carbohydrates that are not broken down by human digestive enzymes in the stomach and small intestine. Fiber passes undigested into the colon where it benefits health by increasing the amount of water and bulk in the intestine, which stimulates gastrointestinal motility; promoting the growth of a healthy microbiota; and slowing nutrient absorption.

4.4 Carbohydrates in the Body

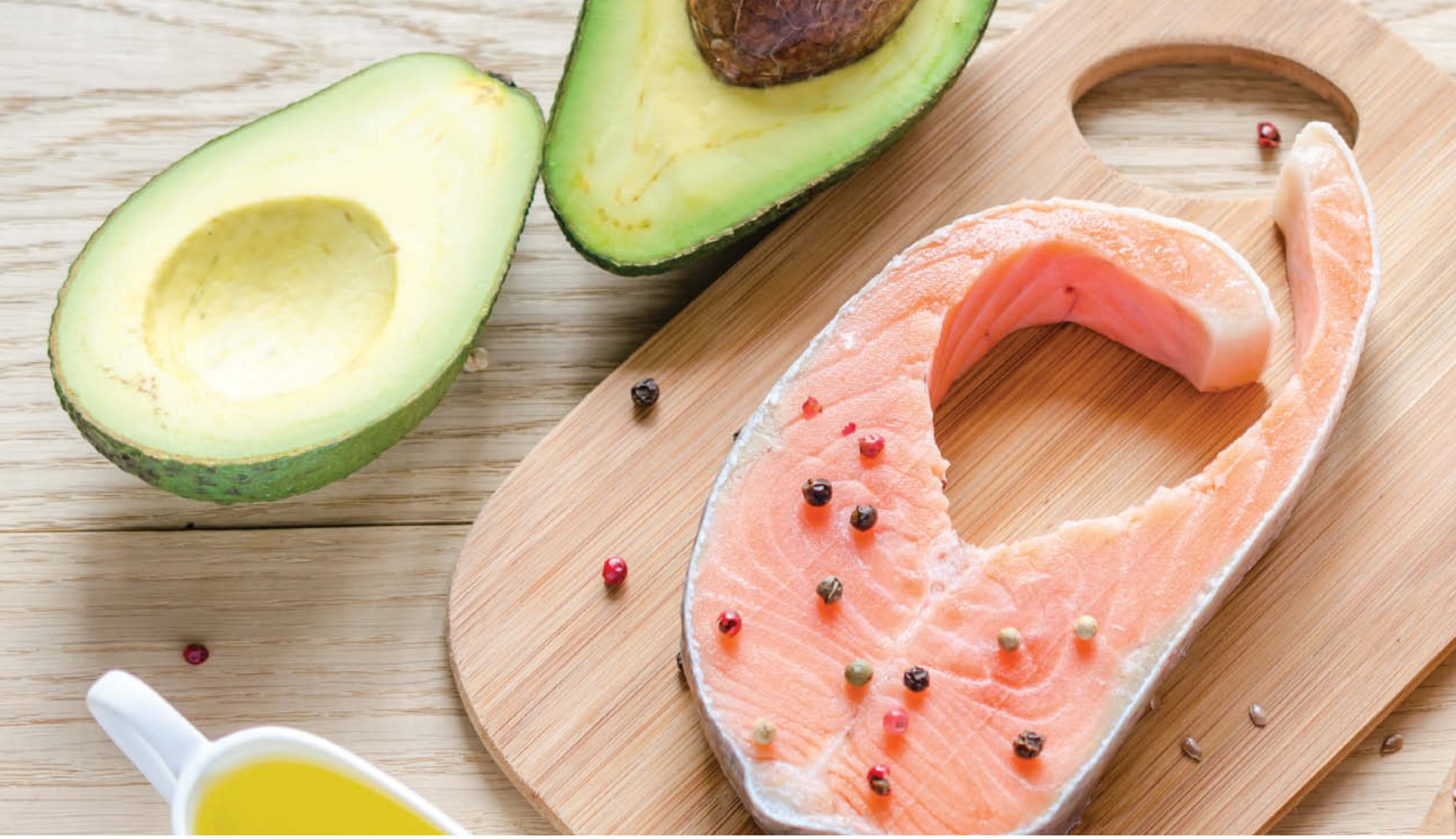
- In the body, glucose provides a source of energy—4 kcal/g. Carbohydrates are also needed for nerve function, for cell communication, and to synthesize DNA and RNA and molecules that provide cushioning and lubrication.
- Blood glucose rises after eating. How quickly and how high blood glucose rises is referred to as glycemic response. Glycemic response can be quantified using glycemic index or glycemic load.
- To ensure a steady supply of glucose to body cells, blood glucose levels are maintained within normal limits by the liver and the hormones insulin and glucagon. When blood glucose rises, insulin is released from the pancreas, allowing muscle and adipose tissue cells to take up the glucose. When blood glucose falls, glucagon is released to increase blood glucose.
- Glucose is metabolized through cellular respiration, which begins with glycolysis or anaerobic metabolism. Glycolysis breaks each six-carbon glucose molecule into 2 three-carbon pyruvate molecules, producing ATP even when oxygen is unavailable. When oxygen is available, aerobic metabolism can proceed. Pyruvate loses a carbon as carbon dioxide to form acetyl-CoA, which is then broken down by the citric acid cycle to form two carbon dioxide molecules. Electrons released at each step pass to the electron transport chain, where their energy is used to generate ATP and water is formed.
- When dietary carbohydrate is limited, metabolism must shift to make sure that glucose is available to the brain and other cells that require glucose as an energy source. Glucose can be obtained from the breakdown of glycogen or from gluconeogenesis, which synthesizes glucose from three-carbon molecules most often derived from amino acid breakdown. When carbohydrate is limited, acetyl-CoA cannot enter the citric acid cycle and instead is used to make ketones.

4.5 Carbohydrates and Health

- Diabetes is an abnormality in blood sugar regulation resulting in high blood glucose levels, which damage tissues and increase the risk of heart disease, kidney failure, blindness, and amputations. Diabetes occurs either because insufficient insulin is produced and/or because there is a decrease in the sensitivity of body cells to insulin. Treatment to maintain glucose in the normal range includes diet, exercise, and medication.
- Hypoglycemia is a condition in which blood glucose falls to abnormally low levels, causing symptoms such as sweating, headaches, and rapid heartbeat. It is a common complication of diabetes treatment.
- When sucrose is present, bacteria in the mouth can form colonies that stick to the teeth. Carbohydrates—particularly simple carbohydrates—are metabolized by the bacteria, producing acids that dissolve the tooth enamel, forming dental caries.
- Carbohydrates contribute to weight gain when total energy intake exceeds needs. Added sugar, particularly from sugar-sweetened beverages, increases the risk of obesity. Unrefined carbohydrates can support weight management by reducing glycemic response and causing a feeling of fullness. Low-carbohydrate diets cause less insulin release, which is believed to favor fat loss. They also cause ketosis, which suppresses appetite and therefore food intake, leading to weight loss.
- High-sugar diets can increase heart disease risk by raising blood lipids. Unrefined carbohydrate sources help lower blood lipids and provide other dietary components that help protect against heart disease.
- Fiber makes the stool larger and softer. This reduces the pressure needed to move material through the colon, lowering the risk of constipation, hemorrhoids, and diverticular disease.
- Cancer cells differ from normal cells because they divide without restraint and are able to grow in areas reserved for other cells. Cells in the colon may be exposed to carcinogens in the colon contents. Fiber may help reduce the risk of colon cancer by decreasing the amount of contact between the cells lining the colon and these carcinogenic substances.

4.6 Meeting Recommendations for Carbohydrate Intake

- Guidelines for healthy diets recommend 45 to 65% of energy from carbohydrates and a fiber intake of 38 g/day for men and 25 g/day for women. Most dietary carbohydrate should come from unrefined food sources, and added sugars should contribute no more than 10% of calorie intake.
- Sources of carbohydrate can be found in all the MyPlate food groups. Unrefined carbohydrates such as whole grains, legumes, fresh fruits and vegetables, and low-fat milk should be selected, and foods high in added sugars, such as baked goods, candy, and sugar-sweetened beverages, should be limited. Food labels can help identify foods that are high in fiber, low in sugar, and sources of whole grains.
- Alternative sweeteners can be used to reduce the amount of added sugar in the diet. They do not contribute to tooth decay and can help keep blood sugar in the normal range. They reduce the energy content of the diet if the calories they eliminate are not added back by consumption of other foods.



CHAPTER OUTLINE

5.1 Fats in Our Food
Sources of Fat in Our Diet
How Dietary Fat Affects Health

5.2 Types of Lipids
Triglycerides and Fatty Acids
Phospholipids
Sterols

5.3 Lipids in the Digestive Tract

5.4 Lipid Transport in the Body
How Lipids Are Transported from the Small Intestine
How Lipids Are Transported from the Liver
How Cholesterol Is Eliminated

5.5 Lipid Functions in the Body
Lipids Provide Structure and Lubrication
How Lipids Regulate Body Processes
How Triglycerides Provide Energy
How Fat Is Stored and Retrieved

5.6 Lipids and Health
Cardiovascular Disease
Dietary Fat and Cancer
Dietary Fat and Obesity

5.7 Meeting Recommendations for Fat Intake
Fat and Cholesterol Recommendations
Translating Recommendations into Healthy Diets
The Role of Reduced-Fat Foods and Fat Replacers

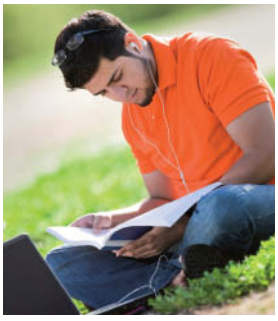
(©iStockphoto)

alexpro9500/Shutterstock

Lipids: Triglycerides, Phospholipids, and Cholesterol

5

CASE STUDY



© Ben Blankenburg/iStockphoto

Kyle is a 20-year-old college student who is worried about his risk of heart disease. After a recent physical, he learned that he is about 25 lb over weight, his percentage body fat is higher than recommended, and his blood cholesterol is slightly elevated. He was told that he should look for ways to improve his cardiovascular health. He knew he was at increased risk because his grandmother died of a heart attack at age 60. Now Kyle has begun to think about how his diet and lifestyle may affect his risk for heart disease.

Kyle knows that he eats a lot of red meat and always drinks whole milk and he doesn't eat much in the way of fruits and vegetables. He has ice cream for dessert after dinner every day. Kyle does get some exercise—he never misses his friends' Tuesday afternoon game of Frisbee and hits the gym every Friday night, but he thinks that it may help to get more exercise. How could a 20-year-old be at risk for heart disease, and how can he lower that risk?

When he tells his friends and family about his health concerns, he is overwhelmed by their diverse responses. His girlfriend, who is a vegetarian, recommends that he eliminate meat from his diet, while his biology lab partner tells him to cut out all fat. His roommate simply suggests that he eat more fish and get to the gym more often. His sister tells him about her experience with the Mediterranean diet. She recommends that he eat pasta with plenty of olive oil every night and his mother says he should stop using margarine because of all the *trans* fat it contains. **All the advice Kyle has received has made him even more confused about how to change his diet.**

5.1 Fats in Our Food

LEARNING OBJECTIVES

- Name two qualities that fat adds to foods.
- Discuss the sources of fat in the American diet.
- Describe how dietary fat affects the risk of chronic disease.

lipids A group of organic molecules, most of which do not dissolve in water. They include fatty acids, triglycerides, phospholipids, and sterols.

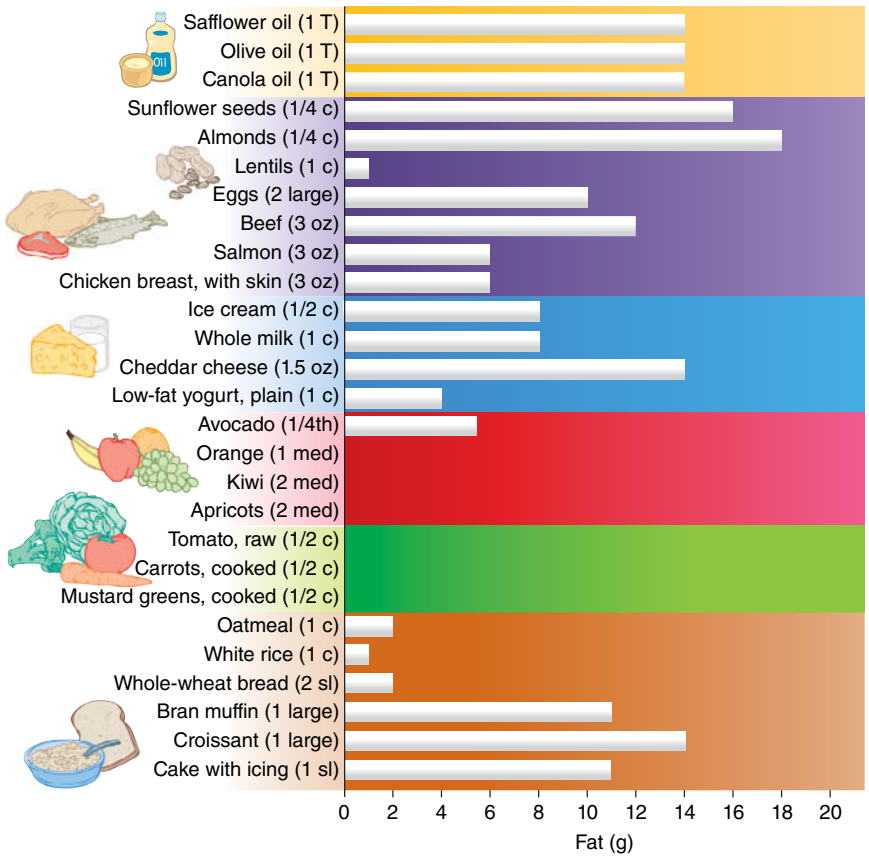
Lipids, the chemical term for what we commonly call fats, make foods appealing by contributing to their texture, flavor, and aroma. Butterfat gives ice cream, cheesecake, and cream cheese a smooth texture and rich taste. Olive oil imparts a unique flavor to salads and many traditional Italian and Greek dishes. Sesame oil gives egg rolls and other Chinese foods their distinctive aroma. But while the fats in our foods contribute to their appeal, they also add calories; fat has 9 kilocalories per gram (kcal/g), compared with 4 kcal/g for carbohydrate or protein. In addition, the types of fats we eat can affect our health; too much of the wrong type of fat can increase the risk of chronic disease.

Sources of Fat in Our Diet

The typical American diet contains about 34% of calories from fat.[1] Some of this fat is naturally present in foods such as meats, dairy products, nuts, seeds, and vegetable oils, but much of it is added to our food in processing or at the table (Figure 5.1A).

FIGURE 5.1 Where's the fat?

A. Most of the fat that is naturally present in foods is found in meats, dairy products, nuts, seeds, and vegetable oils. Processed foods and baked goods are sources of less visible fats. In general fruits, vegetables, and grains are low in fat unless we add fat to them.



© Joe Gough/iStockphoto

145 kcal and 0.2 gram of fat

© Ivan Mateev/iStockphoto

312 kcal and 17 grams of fat

B. French fries start as potatoes, which are low in fat, but when they are immersed in hot oil for frying, they soak up fat. You would have to add four pats of butter to your baked potato for it to have as much fat as a medium order of French fries.

Some of the fats in our food are obvious—the stripes of fat in a slice of bacon sizzling in a frying pan, for example, or the layer of fat around the outside of a sirloin steak. Other visible sources of fat in our diets are the fats we add to foods at the table—the pat of butter melting on a slice of warm toast and the dressing poured over a salad.

Not all sources of dietary fat are obvious. Whole milk, cheese, avocados, and nuts are naturally abundant in fat, and foods such as croissants, doughnuts, cookies, and muffins, which we think of as sources of carbohydrate, may also be quite high in fat. We also add invisible fat when we fry foods (Figure 5.1B).

How Dietary Fat Affects Health

Fat has a bad reputation. Beginning in the 1950s, Americans were told that too much fat made them fat, increased their risk of heart disease, and maybe even increased their risk of cancer. In response to these messages, during the next few decades many Americans switched from whole milk to low-fat, chose chicken in place of beef, consumed fewer eggs, and used less butter and high-fat salad dressing. Nonetheless, the incidence of heart disease and cancer did not decrease, and the number of people who are obese doubled.

Part of the reason for this is that when Americans reduced obvious fats in their diets, they consumed more hidden fats from foods such as pizza, pasta dishes, snack foods, and French fries.[2] Our portion sizes also got bigger, we snacked more, and instead of preparing meals at home we began to eat out and bring home prepared foods that were higher in calories than what we would cook at home.[3,4] Changing the kinds of foods we chose without paying attention to calories promoted weight gain. Changing the sources of fat without paying attention to the type of fat did not protect us from chronic disease. During the past 45 years, the types of fat and the number of grams of fat Americans consume daily have changed little (Figure 5.2). Efforts to reduce chronic disease risk by cutting fat from our diets have failed not only because we haven't really cut our fat intake but also because fat does not deserve its bad reputation. Today, we understand that the types of fat in the diet as well as the overall dietary pattern are more important than total fat intake in terms of chronic disease risk. High intakes of fat from meats, dairy products, and processed fats used in shortening and margarine are associated with a higher incidence of heart disease and certain types of cancer. Diets high in fats from fish, nuts, and vegetable oils seem to protect against chronic disease. A healthy diet includes the right kinds of fats along with plenty of whole grains, fruits, and vegetables.

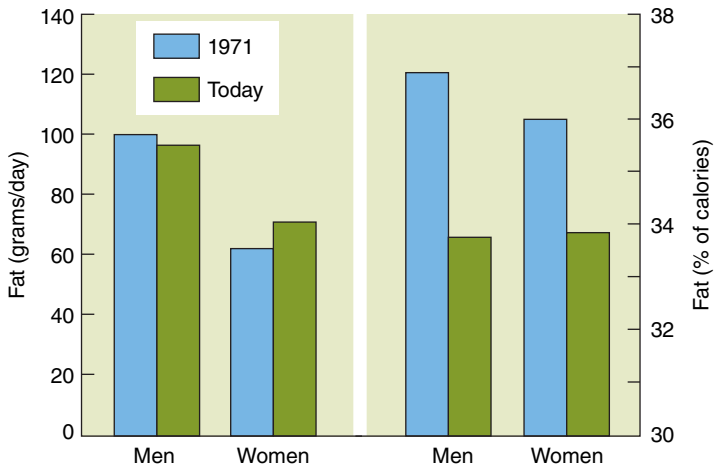


FIGURE 5.2 Changes in fat and energy intake Although the number of calories we eat has increased, the number of grams of fat we eat has remained constant. This caused the percentage of calories from fat to drop from about 37% in 1971 to about 34% today.[1,5,6]

ANALYZE THE DATA

What would happen to our percentage of calories from fat if we reduced our calorie intake but not our fat intake?

5.2 Types of Lipids

LEARNING OBJECTIVES

- Describe the structure of a triglyceride.
- Compare the structures and food sources of saturated, monounsaturated, polyunsaturated, omega-6, omega-3, and *trans* fatty acids.
- Describe how the structure of phospholipids contributes to their function.
- Explain why cholesterol is needed in the body but is not essential in the diet.

triglyceride (triacylglycerol) The major form of lipid in food and in the body. Each consists of three fatty acids attached to a glycerol molecule.

fatty acid An organic molecule made up of a chain of carbons linked to hydrogen atoms with an acid group at one end.

phospholipid A type of lipid that contains phosphorus. The most common is a phosphoglyceride, which is composed of a glycerol backbone with two fatty acids and a phosphate group attached.

sterol A type of lipid with a structure composed of multiple chemical rings.

The majority of the lipids in our food and in our bodies, and what the term *fat* typically refers to, are **triglycerides**. Each triglyceride includes three **fatty acids**. These fatty acids determine the physical properties and health effects of the triglycerides we consume. **Phospholipids** and **sterols** are two other types of lipids that are important in nutrition. The structures of these lipids affect their function in the body and the properties they give to food.

Triglycerides and Fatty Acids

Triglycerides, also known as *triacylglycerols*, consist of a backbone of glycerol with three fatty acids attached, as shown in Figure 5.3. If only one fatty acid is attached to the glycerol, the molecule is called a *monoglyceride* or *monoacylglycerol*, and when two fatty acids are attached, it is a *diglyceride* or *diacylglycerol*.

Structurally, a fatty acid is a chain of carbon atoms with an acid group (COOH) at one end. The other end of the carbon chain is called the *omega* or *methyl end*, and consists of a carbon atom attached to three hydrogen atoms (CH_3). Each of the carbons between is attached to its two neighboring carbons and up to two hydrogen atoms (see Figure 5.3). The physical properties of a fatty acid depend on the length of the carbon chain and the type and location of the bonds between the carbon atoms.

Fatty Acid Chain Length Fatty acids vary in length from a few to 20 or more carbons. Most fatty acids in plants and animals, including humans, are long-chain fatty acids that contain between 14 and 22 carbons. These are found in meats, seafood, and vegetable oils. Medium-chain fatty acids range from 6 to 12 carbons in length and are found in coconut and palm kernel oil. Short-chain fatty acids have fewer than 6 carbons. Milk contains some

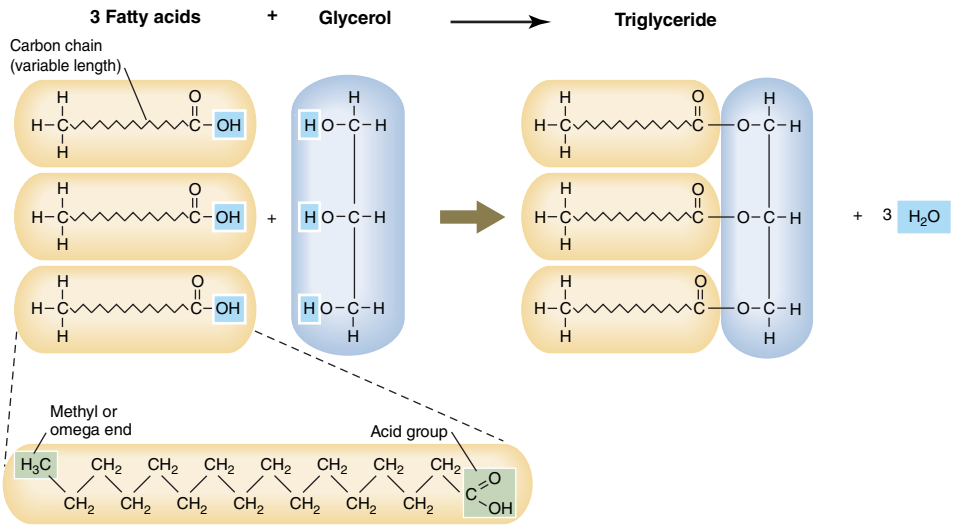


FIGURE 5.3 Formation and structure of triglycerides A triglyceride is formed when three fatty acids bind to a molecule of glycerol. As each bond is formed, a hydrogen atom (H) from the glycerol and a hydroxyl group (OH) from the fatty acid combine to form a molecule of water. The three fatty acids that make up a triglyceride molecule may vary in structure and physical properties.

short-chain fatty acids, and the intestinal microbiota produces them during the breakdown of fiber.

Saturated Fatty Acids Each carbon atom forms four bonds to link it to four other atoms. If a carbon is not bound to four other atoms, double bonds are formed. A fatty acid in which each carbon in the chain is bound to two hydrogen atoms is saturated with hydrogens and is therefore called a **saturated fatty acid** (Figure 5.4). The most common saturated fatty acids are palmitic acid, which has 16 carbons, and stearic acid, which has 18 carbons. These are found most often in animal foods such as meat and dairy products. These long-chain saturated fatty acids tend to be solid at room temperature. Diets high in saturated fatty acids have been associated with an increased risk of heart disease.

Plant oils are generally low in saturated fatty acids. An exception is the **tropical oils**, which include palm oil, palm kernel oil, and coconut oil. These saturated plant oils are called tropical

saturated fatty acid A fatty acid in which the carbon atoms are bound to as many hydrogen atoms as possible and that therefore contains no carbon–carbon double bonds.

tropical oils A term used in the popular press to refer to the saturated oils—coconut, palm, and palm kernel oil—that are derived from plants grown in tropical regions.

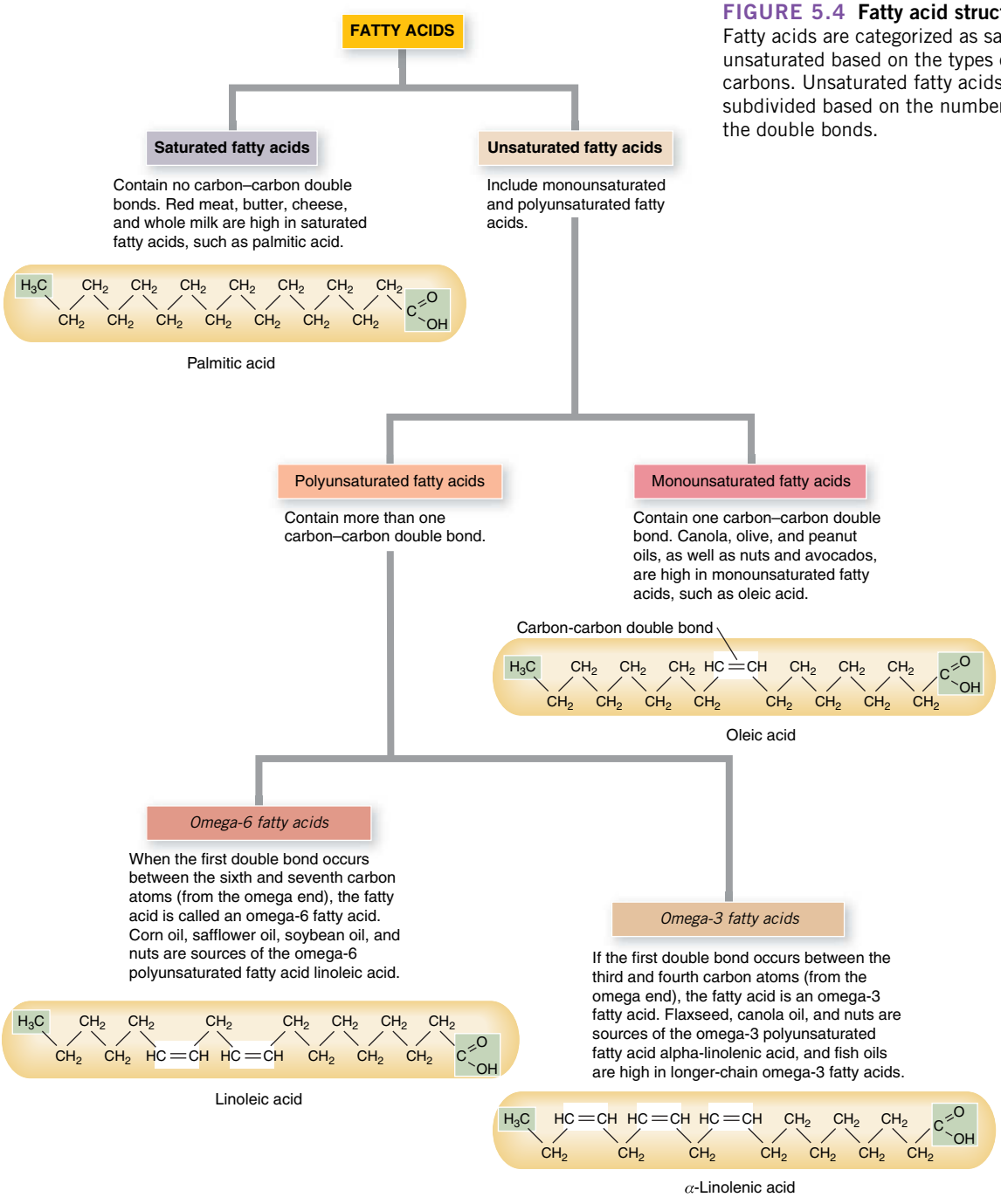


FIGURE 5.4 Fatty acid structures
Fatty acids are categorized as saturated or unsaturated based on the types of bonds between carbons. Unsaturated fatty acids are further subdivided based on the number and locations of the double bonds.

oils because they are found in plants common in tropical climates. Tropical oils can be useful in processed foods such as breakfast cereals, crackers, salad dressings, and cookies because they are less susceptible to spoilage than are more unsaturated oils. Spoilage of fats and oils, referred to as *rancidity*, occurs when the unsaturated bonds in fatty acids are damaged by oxygen. When fats go rancid, they give food an "off" flavor.

Unsaturated Fatty Acids Unsaturated fatty acids contain one or more pairs of carbons that are not saturated with hydrogen atoms. The carbon pairs within the chain that are bound to only one hydrogen form carbon–carbon double bonds (see Figure 5.4). A fatty acid containing one double bond in its carbon chain is called a **monounsaturated fatty acid**. In our diets, the most common monounsaturated fatty acid is oleic acid, which is prevalent in olive and canola oils. A fatty acid with more than one double bond in its carbon chain is said to be a **polyunsaturated fatty acid**. The most common polyunsaturated fatty acid is linoleic acid, found in corn, safflower, and soybean oils. Unsaturated fats are more likely to be liquid at room temperature than saturated fats. Diets high in unsaturated fatty acids are associated with a lower risk of heart disease.

monounsaturated fatty acid A fatty acid that contains one carbon–carbon double bond.

polyunsaturated fatty acid A fatty acid that contains two or more carbon–carbon double bonds.

Omega-3 and Omega-6 Fatty Acids Unsaturated fatty acids are categorized based on the location of the first double bond in the carbon chain. If the first double bond occurs between the third and fourth carbons, counting from the omega end (CH_3) of the chain, the fat is said to be an **omega-3 fatty acid** (see Figure 5.4). Alpha-linolenic acid (α-linolenic acid), found in vegetable oils, and eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), found in fish oils, are omega-3 fatty acids. If the first double bond occurs between the sixth and seventh carbons (from the omega end), the fatty acid is called an **omega-6 fatty acid**. Linoleic acid, found in corn and safflower oils, and arachidonic acid, found in meat and fish, are omega-6 fatty acids. Linoleic acid is the major omega-6 fatty acid in the North American diet. Both omega-3 and omega-6 fatty acids are used to synthesize regulatory molecules in the body, and the biological effect of the molecule synthesized depends on the structure of the fatty acid from which it is made. Therefore, the ratio of omega-6 to omega-3 fatty acids in the diet is important in regulating blood pressure, blood clotting, and immune function, which affect the risk of heart disease.

omega-3 fatty acid A fatty acid containing a carbon–carbon double bond between the third and fourth carbons from the omega end.

omega-6 fatty acid A fatty acid containing a carbon–carbon double bond between the sixth and seventh carbons from the omega end.

***Cis* versus *Trans* Double Bonds** The position of the hydrogen atoms around a double bond also affects the properties of unsaturated fatty acids. Most unsaturated fatty acids found in nature have both hydrogen atoms on the same side of the double bond, called the *cis* configuration. The asymmetry forces a kink or bend in the carbon chain, making it difficult for the triglycerides to pack together (Figure 5.5). When the hydrogen atoms are on opposite sides of the double bond, called the *trans* configuration, the fatty acid is a ***trans* fatty acid**. *Trans* fatty acids can pack tightly like saturated fatty acids and so have a higher melting point than the same fatty acid in the *cis* configuration. When consumed in the diet, *trans* fats raise blood cholesterol levels and increase the risk of heart disease.

Small amounts of *trans* fatty acids occur naturally, and larger amounts are generated by **hydrogenation**. Hydrogenation bubbles hydrogen gas into liquid oil. This causes some of the double bonds in the oil to accept hydrogen atoms and become saturated. Hydrogenation is used to solidify vegetable oils into hard margarine and shortening. Food manufacturers add hydrogenated oils to foods because they are more solid at room temperature and products containing them can be stored longer without becoming rancid. A disadvantage of hydrogenation is that in addition to converting some double bonds into saturated bonds, it transforms some double bonds from the *cis* to the *trans* configuration. Because the consumption of these synthetic *trans* fats increases the risk of developing heart disease, the use of **partially hydrogenated oils** in the food industry has been declining. In June 2015, the FDA passed regulations restricting the addition of partially hydrogenated oils to foods. Food manufacturers have been given three years to comply with these regulations by either removing partially hydrogenated oils from their products or petitioning the FDA to allow their use.[7]

***trans* fatty acid** An unsaturated fatty acid in which the hydrogen atoms are on opposite sides of the double bond.

hydrogenation The process whereby hydrogen atoms are added to the carbon–carbon double bonds of unsaturated fatty acids, making them more saturated.

partially hydrogenated oil A liquid oil that has undergone a process that adds hydrogen atoms to the carbon–carbon bonds of unsaturated fatty acids to make the oil more solid and/or increase the shelf life of the product.

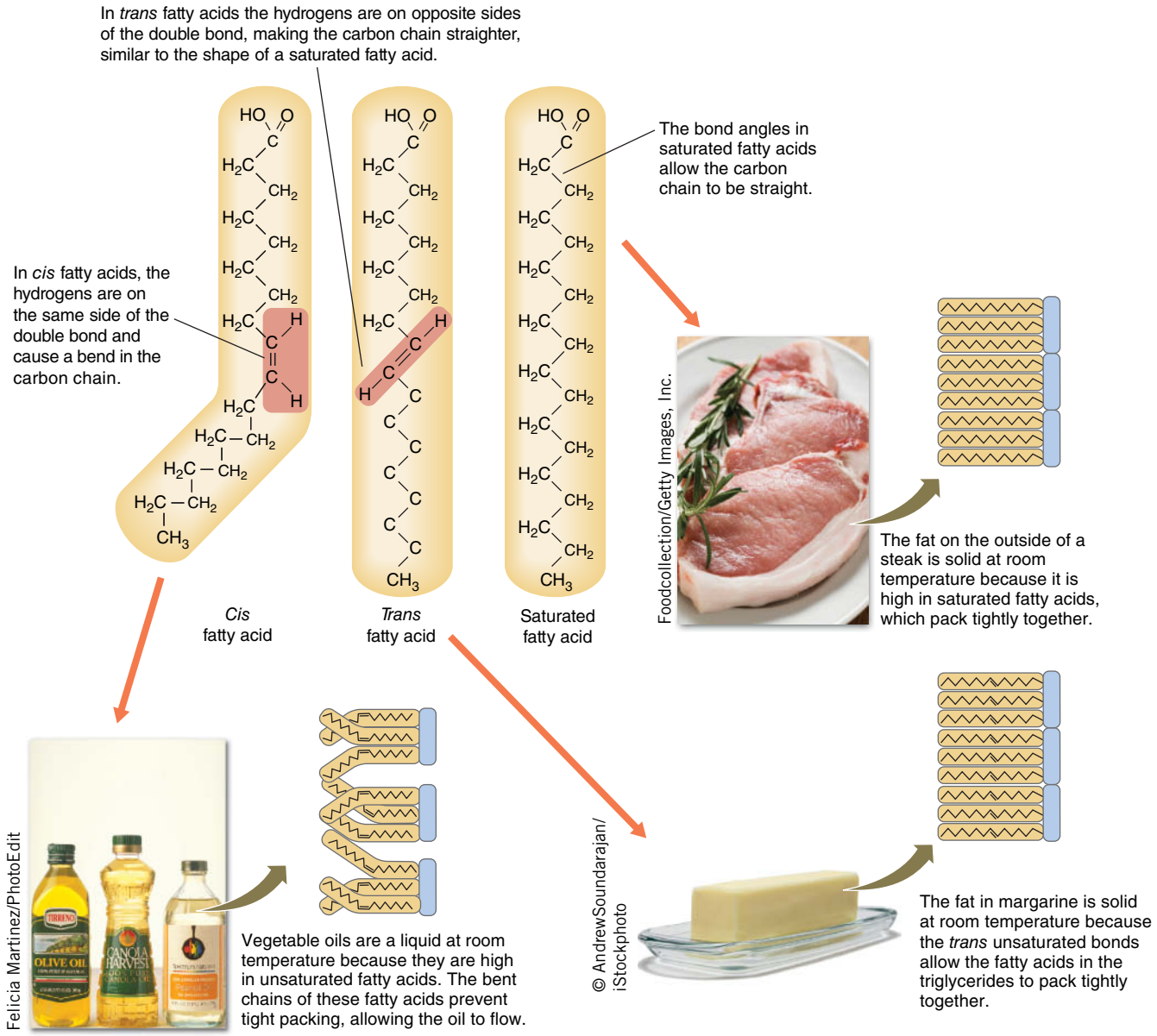


FIGURE 5.5 *Cis*, *trans*, and saturated fatty acids
The types of bonds in fatty acids affect the melting point of the fat. The orientation of the hydrogen atoms around the carbon–carbon double bonds determines how bent or straight the carbon chain is and how tightly the triglycerides can pack together.

Fatty Acids and the Properties of Triglycerides Triglycerides may contain any combination of fatty acids: long, medium, or short chain; saturated or unsaturated; *cis* or *trans* (Figure 5.6). The types of fatty acids in triglycerides determine their texture, taste, and physical characteristics. For example, the amounts and types of fatty acids in chocolate allow it to remain solid at room temperature, snap when bitten into, and then melt quickly and smoothly in the mouth. The triglycerides in red meat contain predominantly long-chain, saturated fatty acids so, as illustrated in Figure 5.5, the fat on a piece of steak is solid at room temperature. The triglycerides in olive oil contain predominantly monounsaturated fatty acids, whereas those in corn oil are mostly polyunsaturated. These fats are liquid at room temperature. The triglycerides in solid margarine made from corn oil have been hydrogenated so they contain more saturated fatty acid and *trans* fatty acids than the original corn oil.

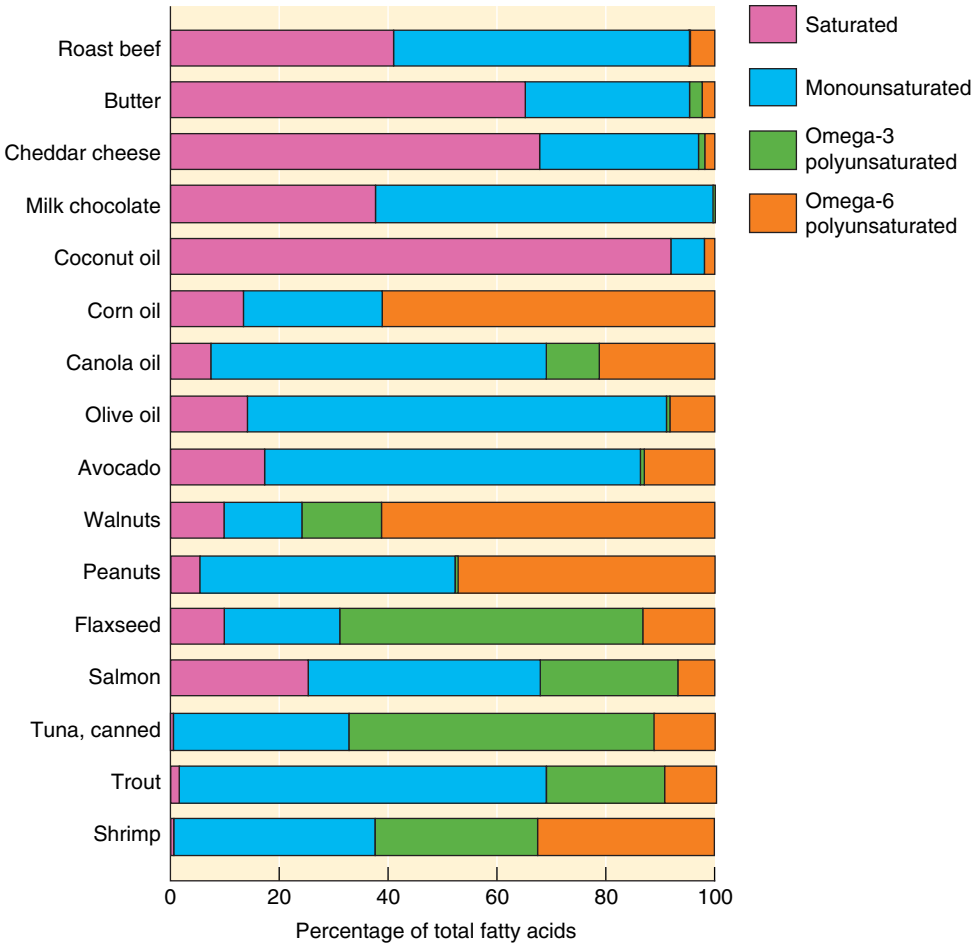


FIGURE 5.6 Fatty acid composition of fats and oils
The fats and oils in our diets contain combinations of saturated, monounsaturated, and omega-3 and omega-6 polyunsaturated fatty acids, shown here as a percentage of the total amount of fat in the food.

Phospholipids

Phospholipids are lipids attached to a chemical group containing phosphorus called a *phosphate group*. **Phosphoglycerides** are the major class of phospholipids. Like triglycerides, they have a backbone of glycerol. However, they have only two fatty acids attached. In place of the third fatty acid is a phosphate group, which is then attached to a variety of other molecules (Figure 5.7A). The fatty acid end of a phosphoglyceride is soluble in fat, whereas the phosphate end is water soluble. This allows phosphoglycerides to mix in both water and fat—a property that makes them important in foods and in the body.

phosphoglyceride A type of phospholipid consisting of a glycerol molecule, two fatty acids, and a phosphate group.

In foods, the ability of phosphoglycerides to mix with both water and fat allows them to act as **emulsifiers** (Figure 5.7B). For example, egg yolks, which contain phosphoglycerides, function as an emulsifier in cake batter, where they allow the oil and water to mix. In the body, phosphoglycerides are an important component of cell membranes. The phosphoglycerides in membranes form a **lipid bilayer**, in which the water-soluble phosphate groups orient toward the aqueous environment inside and outside the cell, while the water-insoluble fatty acids stay in the lipid environment sandwiched in between (Figure 5.7C). This forms the barrier that helps regulate which substances can pass into and out of the cell.

emulsifier A substance that allows water and fat to mix by breaking large fat globules into smaller ones.

lipid bilayer Two layers of phosphoglyceride molecules oriented so that the fat-soluble fatty acid tails are sandwiched between the water-soluble phosphate-containing heads.

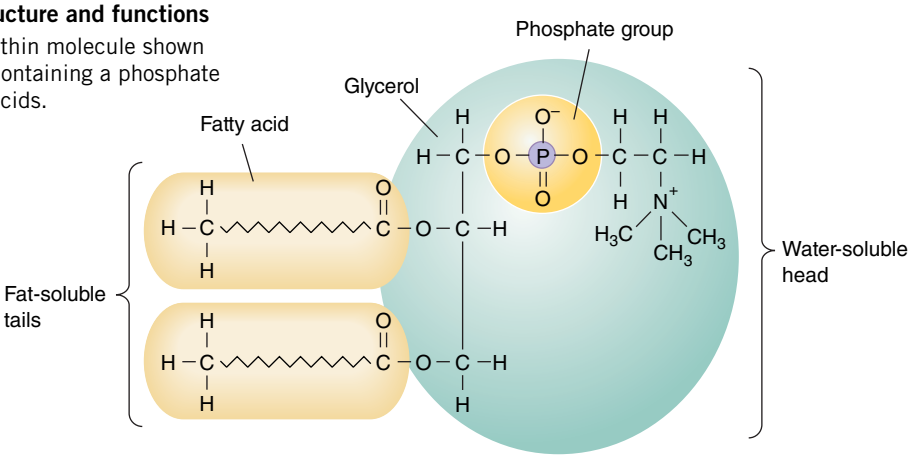
The specific function of a phosphoglyceride depends on the molecule that is attached to the phosphate group. If a molecule of choline is attached, the phospholipid is called **lecithin** (see Figure 5.7A). In the body, lecithin is a major constituent of cell membranes and is required for their optimal function. It is also used to synthesize the neurotransmitter acetylcholine, which is important in the memory center of the brain. Eggs and soybeans are natural sources of lecithin. Lecithin is also used by the food industry as an additive in margarine, salad dressings, chocolate, frozen desserts, and baked goods to keep the oil from separating from the other ingredients.

lecithin A phosphoglyceride composed of a glycerol backbone, two fatty acids, a phosphate group, and a molecule of choline.

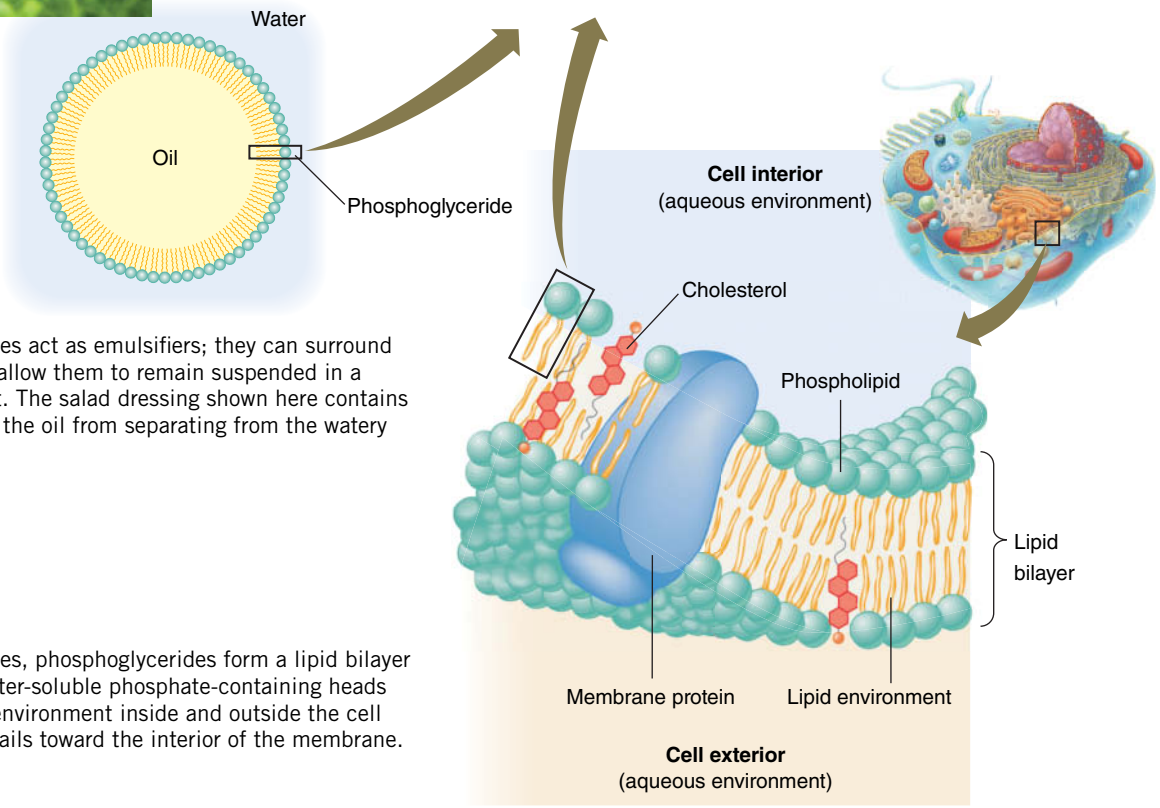
FIGURE 5.7 Phosphoglyceride structure and functions

A. Phosphoglycerides, such as the lecithin molecule shown here, consist of a water-soluble head containing a phosphate group and a lipid-soluble tail of fatty acids.

Jack Anderson/FoodPix/ Getty Images, Inc.



B. Phosphoglycerides act as emulsifiers; they can surround droplets of oil and allow them to remain suspended in a watery environment. The salad dressing shown here contains emulsifiers to keep the oil from separating from the watery ingredients.



C. In cell membranes, phosphoglycerides form a lipid bilayer by orienting the water-soluble phosphate-containing heads toward the watery environment inside and outside the cell and the fatty acid tails toward the interior of the membrane.

Sterols

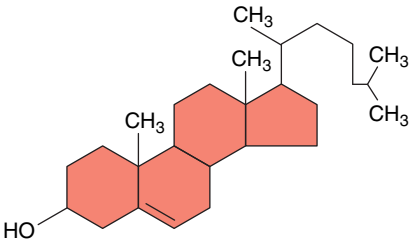
Like most other lipids, sterols do not dissolve well in water. Unlike triglycerides and phosphoglycerides, their structure consists of multiple chemical rings (Figure 5.8A). Sterols are found in both plants and animals. **Cholesterol**, probably the best-known sterol, is only found in animals (Figure 5.8B). Cholesterol is necessary in the body, but because the liver manufactures it, it is not essential in the diet. More than 90% of the cholesterol in the body is found in cell membranes (see Figure 5.7C). It is also part of myelin, the coating on many nerve cells (see Figure 8.19). Cholesterol is needed to synthesize vitamin D in the skin; bile acids, which are emulsifiers in bile; and steroid hormones. The steroid hormones include testosterone and estrogen, which promote growth and the development of sex characteristics, and cortisol, which is released in response to stress and increases blood glucose levels.

cholesterol A lipid that consists of multiple chemical rings and is made only by animal cells.

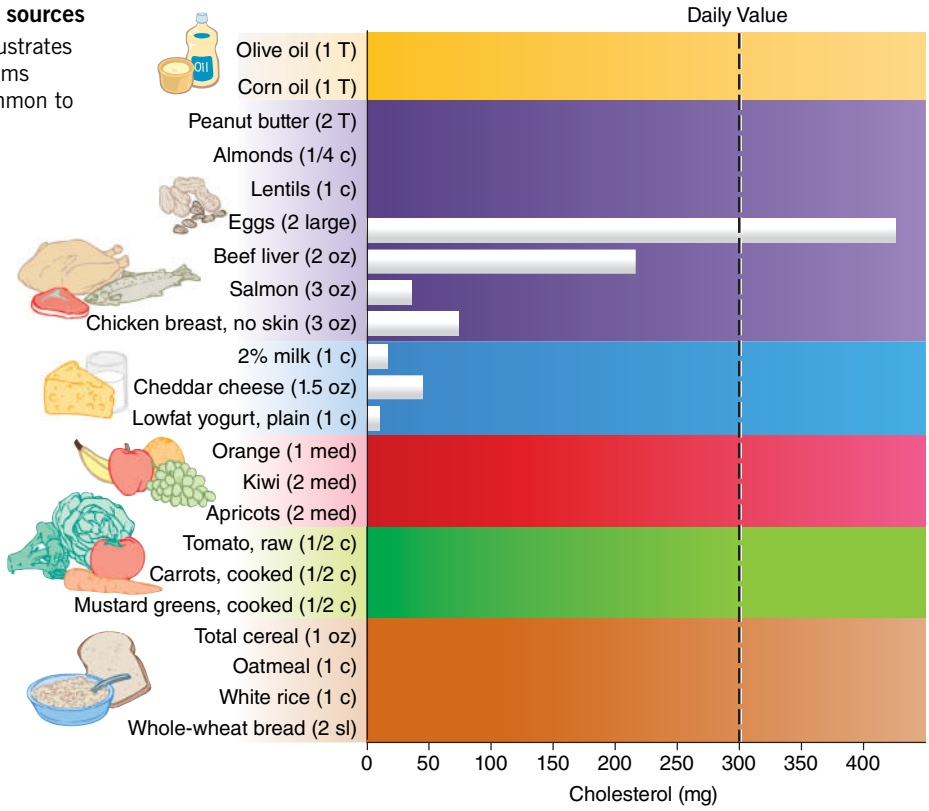
In the diet, cholesterol is found only in foods from animal sources (see Figure 5.8B). Plant foods do not contain cholesterol unless animal products are combined with them in cooking or processing. Plants do contain other sterols, however, and these plant sterols have a role similar to that of cholesterol in animals: They help form plant cell membranes. Plant sterols are found in small quantities in most plant foods; when consumed in the diet, they can help reduce cholesterol levels in the body by decreasing cholesterol absorption from the diet.

FIGURE 5.8 Cholesterol structure and sources

A. The cholesterol structure shown here illustrates the four interconnected rings of carbon atoms forming the backbone structure that is common to all sterols.



B. Egg yolks and organ meats such as liver and kidney are high in cholesterol. Lean red meats and skinless chicken are low in total fat but still contain some cholesterol. Cholesterol is not found in plants.



5.3 Lipids in the Digestive Tract

LEARNING OBJECTIVES

- Describe the steps involved in the digestion of triglycerides.
- Explain how micelles facilitate lipid absorption.

In healthy adults, most of the digestion of dietary fat takes place in the small intestine due to the action of lipid-digesting enzymes called *lipases*. A small amount of triglyceride digestion also occurs in the stomach due to the action of gastric lipase, an enzyme that can act in the acidic environment of the stomach. Gastric lipase is particularly important in infants because it helps digest the fat in milk.[8]

In the small intestine, the bile acids in bile, released from the gallbladder, act as emulsifiers, breaking large lipid droplets into small globules. The triglycerides in these globules are digested by lipases from the pancreas, which break them down into fatty acids and monoglycerides (Figure 5.9). Phospholipids must be partially digested to be absorbed, but cholesterol and fat-soluble vitamins are not digested before they are absorbed. The products of triglyceride digestion, cholesterol, and other fat-soluble substances, including fat-soluble vitamins, mix with bile to form smaller droplets called **micelles**. Micelles have a fat-soluble center surrounded by a coating of bile acids. They facilitate the absorption of lipids into the mucosal cells of the small intestine by allowing these substances to get close enough to the microvilli to diffuse across into the mucosal cells. Most of the bile acids in micelles is also absorbed and returned to the liver to be reused. Once inside the mucosal cell, long-chain fatty acids, cholesterol, and other fat-soluble substances require further processing before they can be transported in the blood.

micelles Particles formed in the small intestine when the products of fat digestion are surrounded by bile acids. They facilitate the absorption of fat.

The fat-soluble vitamins (A, D, E, and K) must be incorporated into micelles to be absorbed. The amounts absorbed can be reduced if dietary fat is very low or if disease, other dietary components, or medications such as the diet drug Alli interfere with fat absorption.

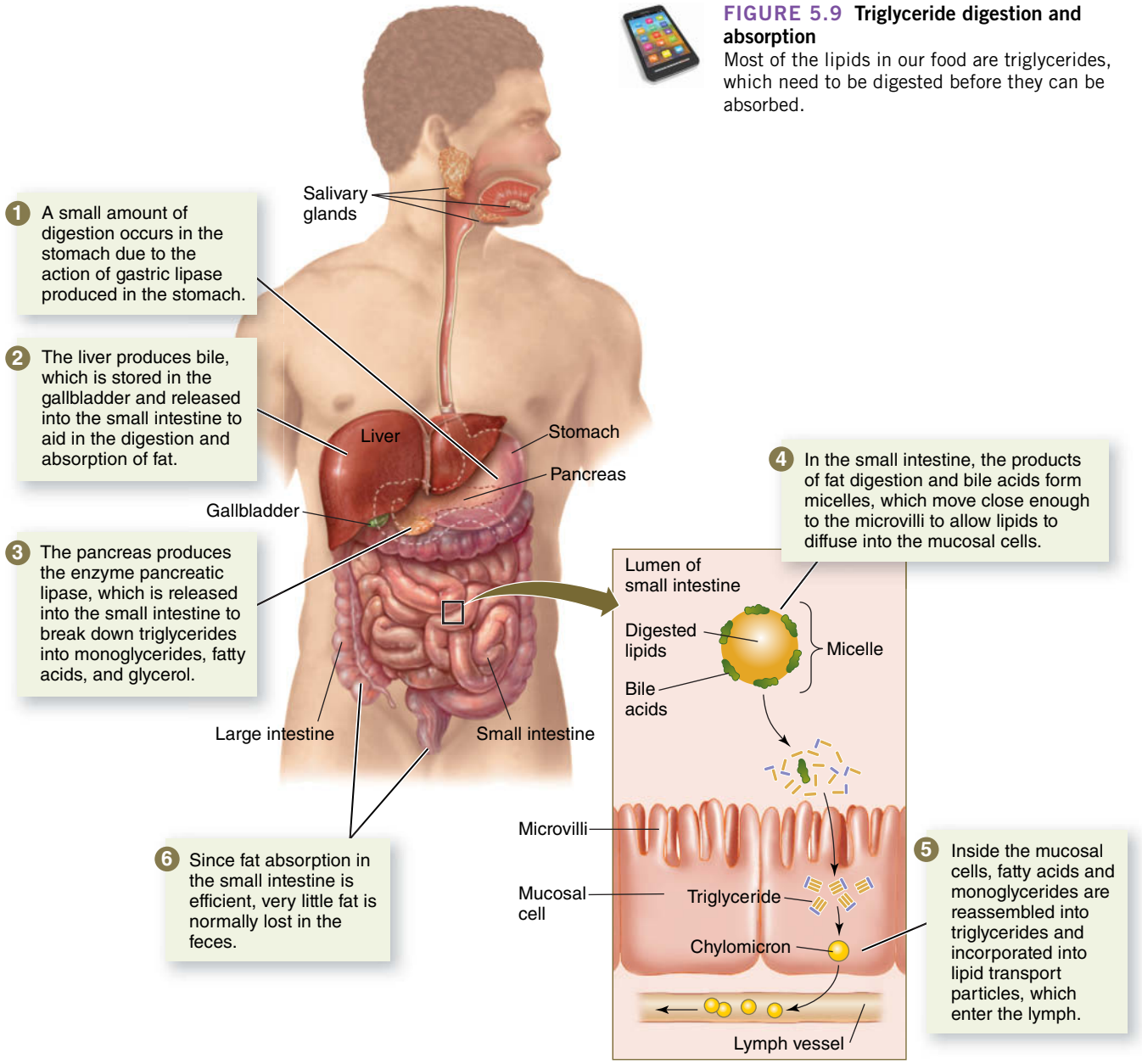


FIGURE 5.9 Triglyceride digestion and absorption
Most of the lipids in our food are triglycerides, which need to be digested before they can be absorbed.

5.4 Lipid Transport in the Body

LEARNING OBJECTIVES

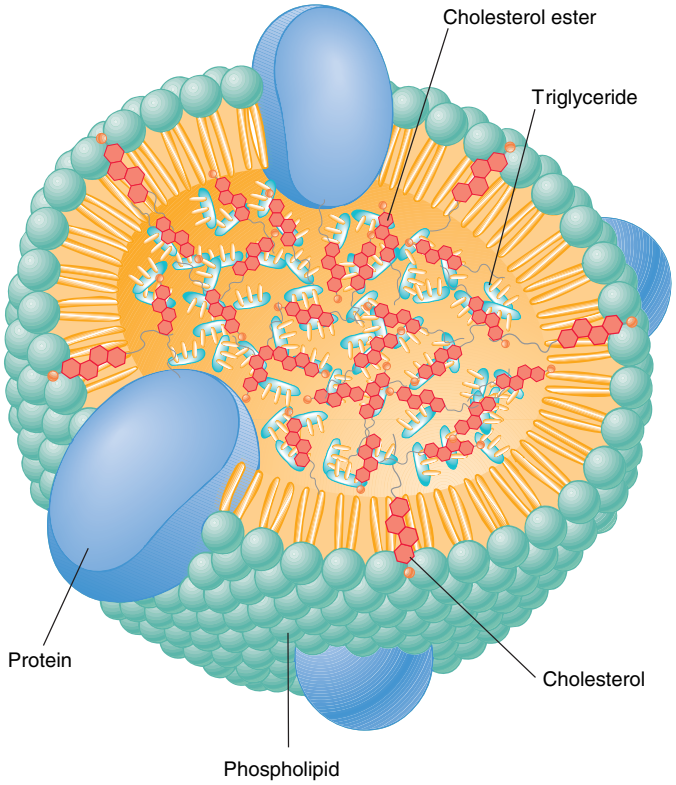
- Describe how lipids are transported in the blood and enter cells.
- Compare and contrast the functions of LDLs and HDLs.

How lipids are absorbed and transported throughout the body depends on their solubility in water. Short- and medium-chain triglycerides are water soluble. They are easily digested and the resulting short- and medium-chain length fatty acids do not require micelles to be absorbed. Once absorbed, they pass directly into the blood and travel to the liver and then to cells throughout the body. Lipids that are not soluble in water, such as long-chain fatty acids, cholesterol, and fat-soluble vitamins, cannot enter the bloodstream directly so they must be packaged for transport. They are covered in a water-soluble envelope of protein, phospholipids, and cholesterol to form **lipoproteins** (Figure 5.10). Lipoproteins vary in size and composition. Different types transport dietary lipids from the small intestine to body cells, from the liver to body cells, and from body cells back to the liver for disposal.

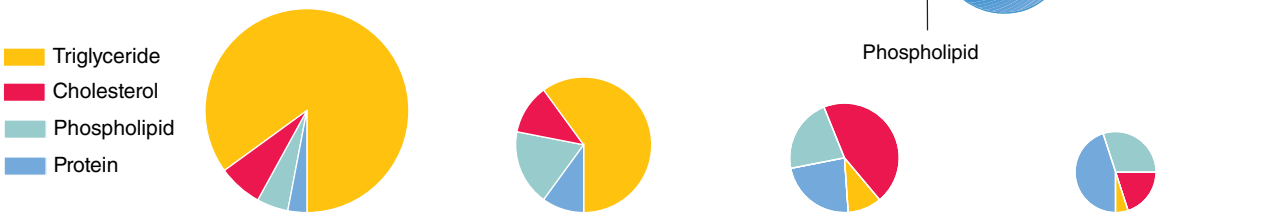
lipoprotein A particle containing a core of triglycerides and cholesterol surrounded by a shell of protein, phospholipids, and cholesterol that transports lipids in blood and lymph.

FIGURE 5.10 Lipoprotein structure and composition

A. Lipoproteins consist of a core of triglycerides and cholesterol esters (cholesterol with a fatty acid attached) surrounded by a shell of proteins, phospholipids, and cholesterol. The phospholipids orient with their fat-soluble tails toward the interior and their water-soluble heads toward the outside, allowing water-insoluble lipids to be transported in the aqueous environment of the blood.



B. Lipoproteins, such as chylomicrons, very-low-density lipoproteins (VLDLs), low-density lipoproteins (LDLs), and high-density lipoproteins (HDLs), vary in size and in the proportions of triglyceride, cholesterol, phospholipid, and protein. The less triglyceride and more protein a lipoprotein has, the greater its density.



Chylomicron	VLDL	LDL	HDL
Chylomicrons are the largest lipoproteins and contain the greatest proportion of triglycerides.	VLDLs are smaller than chylomicrons but still contain a high proportion of triglycerides.	LDLs contain a higher proportion of cholesterol than do other lipoproteins.	HDLs are the densest lipoproteins due to their high protein content; they contain a moderate amount of cholesterol.

How Lipids Are Transported from the Small Intestine

To be transported from the small intestine, long-chain fatty acids and monoglycerides must first be assembled into triglycerides by the mucosal cell. These triglycerides are then combined with cholesterol, phospholipids, and a small amount of protein to form lipoproteins called **chylomicrons** (see Figure 5.10B). Chylomicrons are too large to enter the capillaries in the villi of the small intestine, so they pass from the intestinal mucosa into the lymphatic system, which then delivers them to the blood without first passing through the liver.

As chylomicrons circulate in the blood, the enzyme **lipoprotein lipase**, present on the surface of the cells lining the blood vessels, breaks the triglycerides down into fatty acids and glycerol, which enter the surrounding cells. The fatty acids can be either used as fuel or resynthesized into triglycerides for storage. What remains of the chylomicron is a chylomicron remnant composed mostly of cholesterol and protein. This goes to the liver and is disassembled (Figure 5.11).

chylomicron A lipoprotein that transports lipid from the mucosal cells of the small intestine and delivers triglycerides to other body cells.

lipoprotein lipase An enzyme that breaks down triglycerides into fatty acids and glycerol; attached to the cell membranes of cells that line the blood vessels.

very-low-density lipoprotein (VLDL) A lipoprotein assembled by the liver that carries lipids from the liver and delivers triglycerides to body cells.

How Lipids Are Transported from the Liver

The liver is the major lipid-producing organ in the body. Here excess protein and carbohydrate, as well as alcohol, can be broken down and used to make triglycerides or cholesterol. Triglycerides made in the liver are incorporated into lipoprotein particles called **very-low-density lipoproteins (VLDLs)** (see Figure 5.10B). Cholesterol synthesized in the liver or delivered in chylomicron remnants can be incorporated into VLDLs or can be used to make bile acids. VLDLs transport lipids out of the liver and deliver triglycerides to body cells. As with chylomicrons, the enzyme lipoprotein lipase breaks down the triglycerides in VLDLs so that the fatty acids can be taken up by surrounding cells

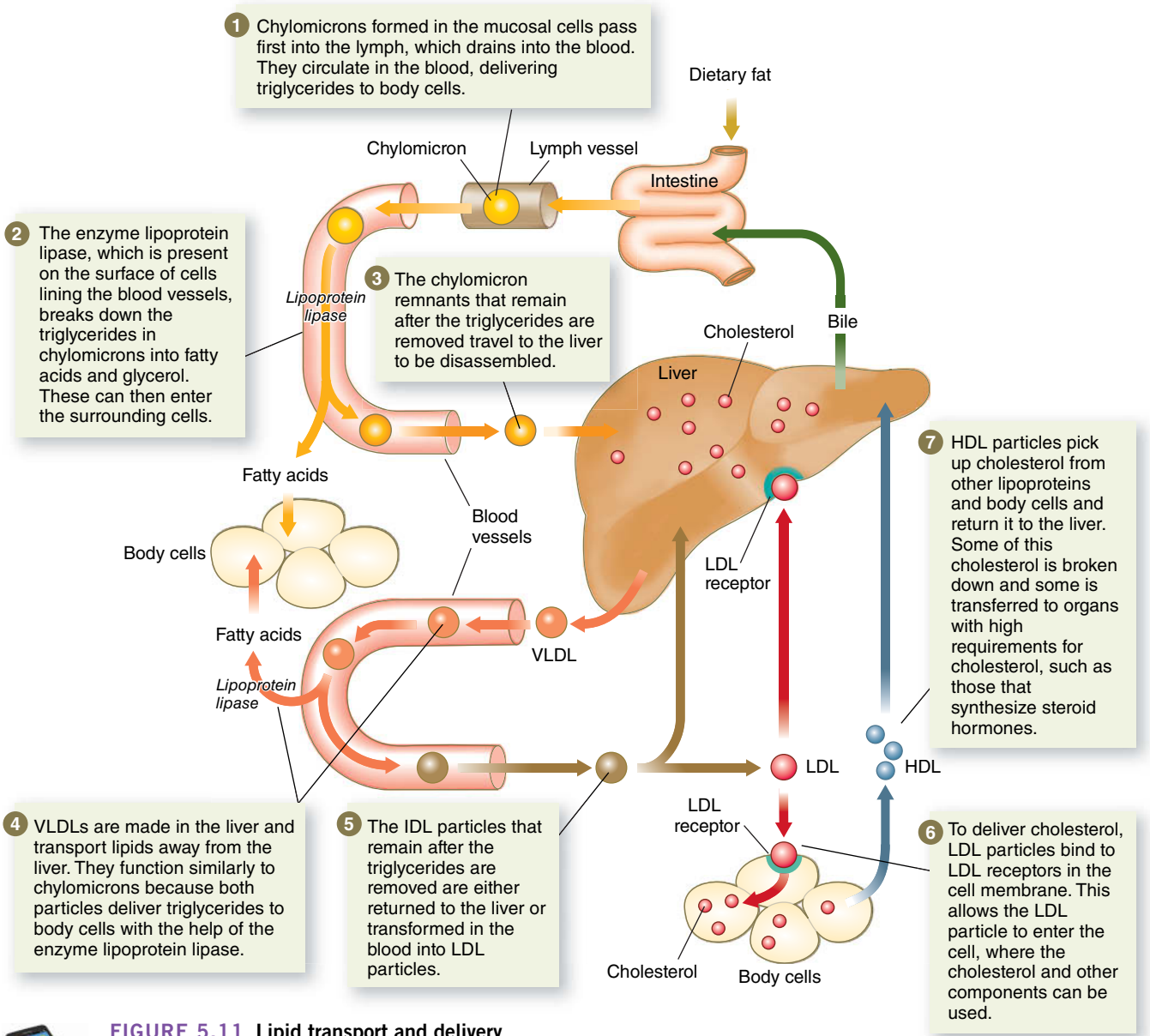


FIGURE 5.11 Lipid transport and delivery
Lipids absorbed from the intestine are transported in the blood as lipoproteins. Chylomicrons and VLDLs transport triglycerides and deliver them to body cells. LDLs transport and deliver cholesterol, while HDLs help return cholesterol to the liver for reuse or elimination.

(see Figure 5.11). Once the triglycerides are removed from the VLDLs, a denser, smaller, intermediate-density lipoprotein (IDL) remains. About two-thirds of the IDLs are returned to the liver, and the rest are transformed in the blood into **low-density lipoproteins (LDLs)**. LDLs contain less triglyceride and therefore proportionally more cholesterol than VLDLs (see Figure 5.10B). LDLs are the primary cholesterol delivery system for cells.

For cholesterol to enter cells, the LDLs must be taken up by the cells. For this to occur, a protein on the surface of the LDL particle called *apoprotein B* (*apo B*) must bind to a receptor protein on the cell membrane, called an **LDL receptor**. This binding allows LDLs to be removed from the blood circulation and enter cells where they are broken apart and their cholesterol and other components can be used (see Figure 5.11). If the amount of LDL cholesterol in the blood exceeds the amount that can be taken up by cells—due to either too much LDL cholesterol or too few LDL receptors—the result is a high level of LDL cholesterol. High levels of LDL particles in the blood have been associated with an increased risk for heart disease (see **Science Applied: How a Genetic Disease Led to Treatment for High Blood Cholesterol**).

low-density lipoprotein (LDL) A lipoprotein that transports cholesterol to cells. Elevated LDL cholesterol increases the risk of cardiovascular disease.

LDL receptor A protein on the surface of cells that binds to LDL particles and allows their contents to be taken up for use by the cell.

SCIENCE APPLIED

How a Genetic Disease Led to Treatment for High Blood Cholesterol

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

Children with a rare form of the inherited disease familial hypercholesterolemia have blood cholesterol levels that range from 650 to 1000 mg/100 mL—six times the normal level. Their blood cholesterol levels are so high that it deposits in the tissues, forming soft, raised bumps on the skin called *xanthomas* (see photo). The elevated cholesterol damages blood vessels, leading to premature atherosclerosis. Chest pain, heart attacks, and death are common before the age of 15, and it is rare for individuals with this disease to survive past age 30.[9,10] Research into the causes of this disease led Drs. Michael Brown and Joseph Goldstein to a discovery that is key to our understanding of how blood cholesterol is regulated.

THE SCIENCE

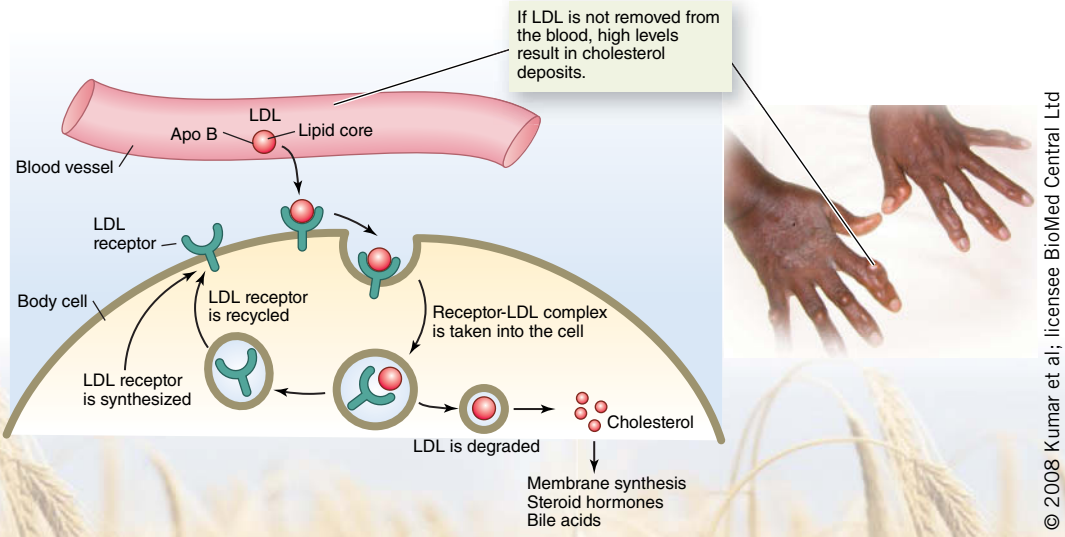
To study familial hypercholesterolemia, Brown and Goldstein grew cells in culture. They observed that when LDL cholesterol was added to the culture medium, the rate of cholesterol synthesis in cells from normal subjects decreased. In cells from individuals with familial hypercholesterolemia, however, the presence of LDL in the medium did not cause a decrease in cholesterol synthesis.[11] By using radioactively labeled LDL particles, Brown and Goldstein were able to demonstrate that in cells from normal individuals, LDL particles bind to the cells and are removed from the surrounding media. In individuals with familial hypercholesterolemia, the LDL particles are unable to bind to the cells and therefore cholesterol cannot be removed from the media.[12] The binding of LDL to the cell was found to be due to a membrane protein, named the *LDL receptor*. This protein is defective in individuals with familial hypercholesterolemia.

THE APPLICATION

The discovery of the LDL receptor led to an understanding of how the body controls levels of cholesterol in cells and in the blood. The LDL receptor is a cell surface protein; it is synthesized by the cell and inserted into the cell membrane. The binding of an LDL particle to the receptor results in the movement of the LDL particle into the cell (see figure). When cells are deprived of cholesterol, the number of receptors increases and cholesterol synthesis in the cell increases. Conversely, when cholesterol accumulates in cells, the synthesis of LDL receptors and cholesterol decreases.[13]

Brown and Goldstein recognized that the number of receptors in the liver could be increased by lowering the cholesterol content of liver cells. In 1976, a compound was isolated from mold that blocks cholesterol synthesis in the liver and stimulates the synthesis of LDL receptors.[14] This class of drug, collectively called *statins*, was shown to lower plasma LDL levels, which in turn led to protection from heart attacks. By 2003, the statin drug Lipitor was the best-selling drug in history.[15] In 2013, the American Heart Association and American College of Cardiologists recommended statins along with lifestyle changes to reduce the risk of heart attacks; it is estimated this could result in 30 million Americans taking these drugs.[16] The work of Brown and Goldstein enabled us to understand how these powerful drugs affect cholesterol metabolism.

THINK CRITICALLY: Do people who are taking statin drugs also need to follow diet and exercise recommendations to reduce their risk of heart attacks? Why or why not?



© 2008 Kumar et al; licensee BioMed Central Ltd

How Cholesterol Is Eliminated

Because most body cells have no system for breaking down cholesterol, it must be returned to the liver to be eliminated from the body. This reverse cholesterol transport is accomplished by the densest of the lipoprotein particles, called **high-density lipoproteins (HDLs)** (see Figure 5.10). These particles originate from the intestinal tract and liver and circulate in the blood, picking up cholesterol from other lipoproteins and body cells. They function as a temporary storage site for lipids. Some of the cholesterol in HDLs is taken directly to the liver for disposal, and some is transferred to organs that have a high requirement for cholesterol, such as those involved in steroid hormone synthesis (see Figure 5.11). High levels of HDL in the blood help prevent cholesterol from depositing in the artery walls and are associated with a reduction in heart disease risk.

high-density lipoprotein (HDL) A lipoprotein that picks up cholesterol from cells and transports it to the liver so that it can be eliminated from the body. A high level of HDL decreases the risk of cardiovascular disease.

5.5 Lipid Functions in the Body

LEARNING OBJECTIVES

- List four functions of lipids in the body.
- Explain why enough of, and the right balance of, omega-3 and omega-6 fatty acids are needed in the diet.
- Describe how fatty acids are used to generate ATP.
- Discuss how fat is stored after a meal and how stored fat is retrieved between meals and during fasting.

Lipids are necessary to maintain health. In our diet, fat is needed to absorb fat-soluble vitamins and is a source of essential fatty acids. In our bodies, lipids form structural and regulatory molecules, are stored as an energy reserve, and are broken down via cellular respiration to provide energy in the form of ATP.

adipose tissue Tissue found under the skin and around body organs that is composed of fat-storing cells.

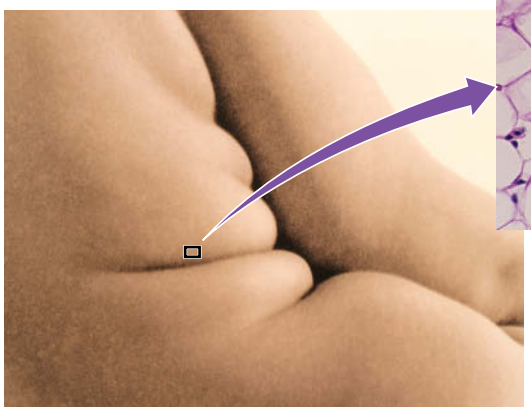
adipocyte A fat-storing cell.

Lipids Provide Structure and Lubrication

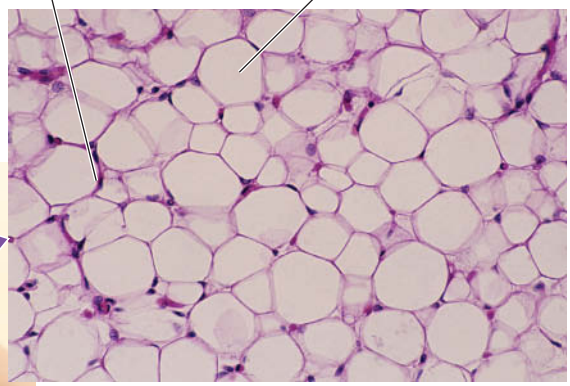
Most of the lipids in the human body are triglycerides stored in **adipose tissue**, which is composed of **adipocytes**. Adipose tissue lies under the skin and around internal organs. Triglycerides in adipose tissue provide a lightweight energy storage molecule, cushion our internal organs, insulate the body from changes in temperature, and contribute to our body shape and contours (Figure 5.12).

FIGURE 5.12 Adipose tissue

A. The amount and location of adipose tissue affect our body size and shape. When people have liposuction to slim their hips or flatten their tummy, the surgeon is actually vacuuming out fat cells from the adipose tissue in the region.



Christina Pedrazzini/Science Source



Ed Reschke/Getty Images, Inc.

B. Adipocytes contain large droplets of triglyceride that push the other cell components to the perimeter of the cell. As weight is gained, the triglyceride droplets enlarge.

Triglycerides also make up the oils that lubricate body surfaces. For example, oil glands in the skin help to waterproof it and keep it soft and supple.

Cholesterol and phospholipids are also important structural molecules. Cholesterol is particularly important in the brain and nervous system, where it is used to form myelin, an insulating coating around nerves. Cholesterol and phospholipids form the structure of all cell membranes and therefore define the boundaries of cells and partition off their organelles.

How Lipids Regulate Body Processes

Cholesterol and fatty acids are both used to synthesize regulatory molecules in the body. Cholesterol, either consumed in the diet or made in the liver, is used to make steroid hormones, which include sex hormones and stress hormones. Polyunsaturated fatty acids are used to make hormone-like molecules that help regulate blood pressure, blood clotting, and other body parameters. However, unlike cholesterol, which is synthesized by the liver, the body cannot make all the fatty acids it needs, so certain ones must be consumed in the diet.

Essential Fatty Acids

essential fatty acid A fatty acid that must be consumed in the diet because it cannot be made by the body or cannot be made in sufficient quantities to meet needs.

The human body is capable of synthesizing most of the fatty acids it needs from glucose or other sources of carbon, hydrogen, and oxygen. Humans, however, are not able to synthesize double bonds in the omega-6 and omega-3 positions. Therefore, the fatty acids linoleic acid (omega-6) and α-linolenic acid (omega-3) are **essential fatty acids**. If the diet is low in linoleic acid and/or α-linolenic acid, other fatty acids that the body would normally synthesize from them become dietary essentials as well. Arachidonic acid is an omega-6 fatty acid synthesized from linoleic acid. Arachidonic acid is considered essential only when the diet is low in linoleic acid. EPA and DHA are omega-3 fatty acids synthesized from α-linolenic acid (Figure 5.13).

essential fatty acid deficiency A condition characterized by dry scaly skin and poor growth that results when the diet does not supply sufficient amounts of the essential fatty acids.

Essential fatty acids and the longer-chain fatty acids made from them are important for the formation of the phospholipids that give cell membranes their structure and functional properties. Therefore, they are essential for growth, development, fertility, and maintaining the structure of red blood cells and cells in the skin and nervous system. DHA is particularly important in the retina of the eye. Both DHA and arachidonic acid are needed to synthesize cell membranes in the central nervous system and are therefore important for normal brain development in infants and young children. Long-chain fatty acids also serve as regulators of energy metabolism through their role in gene expression.[17]

If adequate amounts of linoleic and α-linolenic acid are not consumed, an **essential fatty acid deficiency** will result. Symptoms include dry scaly skin, liver abnormalities, poor healing of wounds, growth failure in infants, and impaired vision and hearing. Because the requirement for essential fatty acids is well below the typical intake in the United States, essential fatty acid

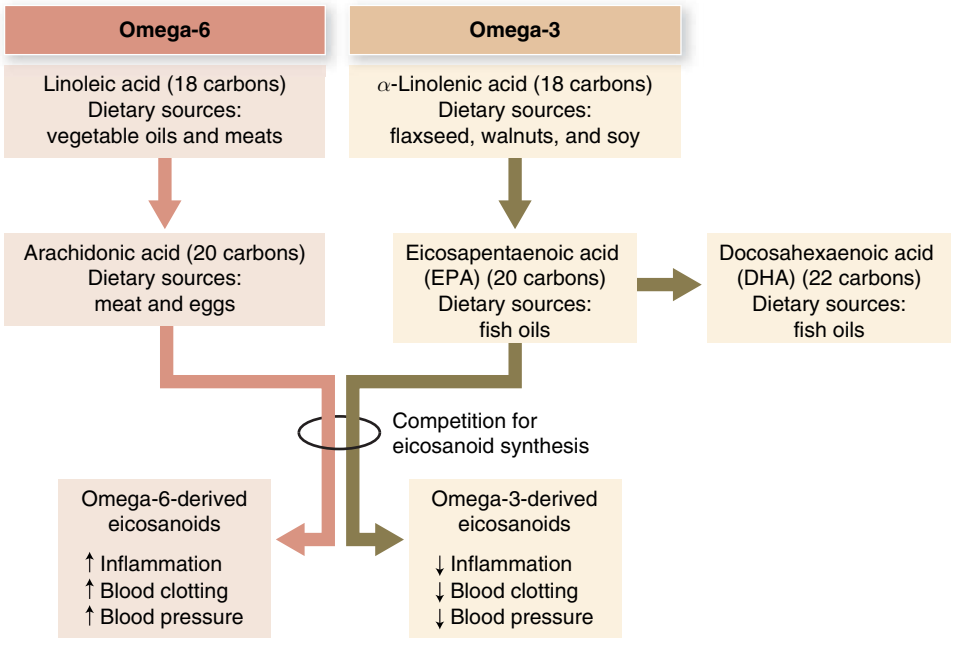


FIGURE 5.13 Molecules synthesized from essential fatty acids
If the diet contains enough of the essential fatty acids linoleic acid and α-linolenic acid, adequate amounts of the longer-chain omega-6 and omega-3 fatty acids can usually be synthesized. Arachidonic acid and EPA compete for the enzymes that synthesize eicosanoids, so more EPA-derived eicosanoids will be made when more EPA is consumed or synthesized.

deficiencies are rare in this country. However, deficiencies have been seen in infants and young children fed very low-fat diets and in individuals who are unable to absorb lipids.

Eicosanoid Synthesis and Function Getting enough essential fatty acids in your diet will prevent deficiency, but the ratio of dietary omega-6 to omega-3 fatty acids also affects your health. This is because the omega-6 and omega-3 polyunsaturated fatty acids made from them are used to make hormone-like molecules called **eicosanoids**. Eicosanoids help regulate blood clotting, blood pressure, immune function, and other body processes. The effect an eicosanoid has on these functions depends on the fatty acid from which it is made. For example, when the omega-6 fatty acid arachidonic acid is the starting material, the eicosanoid synthesized increases blood clotting, whereas when the eicosanoid is made from the omega-3 fatty acid EPA, it decreases blood clotting (see Figure 5.13). Omega-3 fatty acids, particularly EPA and DHA, have anti-inflammatory properties. Some of this effect is due to the amounts and types of eicosanoids made, and some is due to the effects these fatty acids have on other aspects of cell function. Since **inflammation** plays a role in the progression of heart disease, a nutrient with anti-inflammatory properties would protect against heart disease. Epidemiological studies and feeding trials both provide evidence for a beneficial effect of omega-3 fatty acids on the manifestations of heart disease and stroke.[18] The anti-inflammatory properties of omega-3 fatty acids have also been shown to be of benefit in other chronic diseases that involve inflammatory processes such as rheumatoid arthritis, inflammatory bowel disorders, and cancer.[19]

eicosanoids Regulatory molecules, including prostaglandins and related compounds, that can be synthesized from omega-3 and omega-6 fatty acids.

inflammation The response of a part of the body to injury that increases blood flow with an influx of white blood cells and other chemical substances to facilitate healing. It is characterized by swelling, heat, redness, pain, and loss of function.

The ratio of dietary omega-6 to omega-3 essential fatty acids affects the balance of these fatty acids in the tissues and therefore the ratio of the types of eicosanoids made from them (see Figure 5.13). To maintain a healthy balance in the body, a dietary ratio of linoleic to α-linolenic acid of 5:1 to 10:1 is recommended. To provide this ratio, a diet that contains 20 g of linoleic acid would need to include 2 to 4 g of α-linolenic acid. However, if the diet contains plenty of arachidonic acid, EPA, and DHA, which are made from linoleic and α-linolenic acids, the actual ratio of linoleic to α-linolenic acid is of less concern.[5] The American diet contains plenty of omega-6 fatty acids, so to get a healthier mix Americans should increase their intake of omega-3s from foods such as fish, walnuts, flaxseed, leafy green vegetables, and soybean and canola oils (see Figure 5.6).[20]

How Triglycerides Provide Energy

Triglycerides consumed in the diet can be used as an immediate source of energy or stored in adipose tissue for future use. The majority of ATP produced from triglyceride metabolism is from the breakdown of fatty acids. Only a small amount is derived from glycerol. In the first step of fatty acid breakdown, called **beta-oxidation (β-oxidation)**, the carbon chain of fatty acids is split into two-carbon units that form acetyl-CoA and release high-energy electrons (Figure 5.14).

beta-oxidation (β-oxidation) The first step in the production of ATP from fatty acids. This pathway breaks the carbon chain of fatty acids into two-carbon units that form acetyl-CoA and release high-energy electrons that are passed to the electron transport chain.

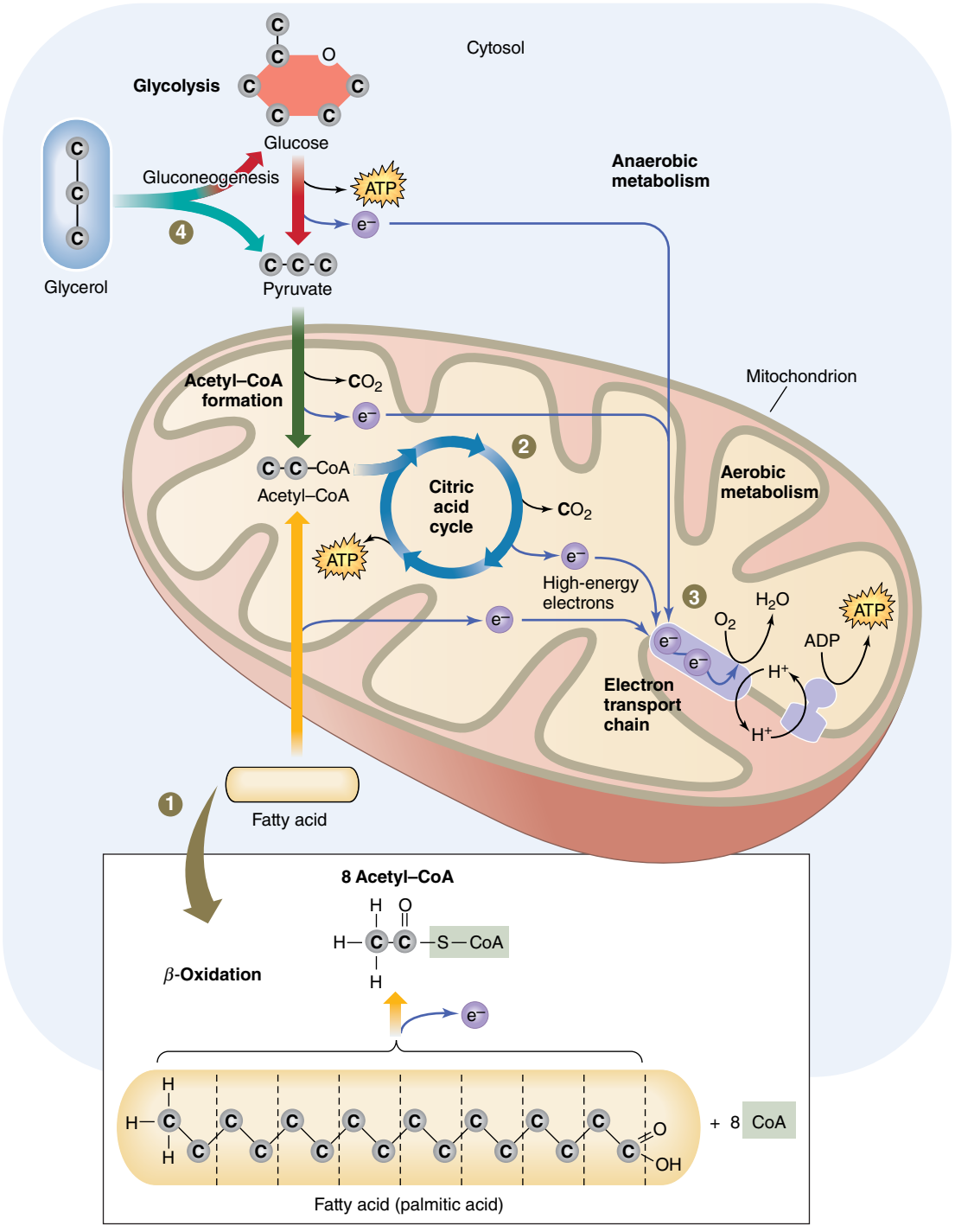
To enter the citric acid cycle, acetyl-CoA from β-oxidation combines with oxaloacetate, a four-carbon molecule derived from carbohydrate, to form a six-carbon molecule called *citric acid*. The reactions of the citric acid cycle then remove one carbon at a time to produce carbon dioxide (see Figure 5.14). After two carbons have been removed in this manner, a four-carbon oxaloacetate molecule is re-formed and the cycle can begin again. The high-energy electrons released in β-oxidation and the citric acid cycle are shuttled to the last stage of cellular respiration, the electron transport chain. Molecules here accept electrons and pass them down the chain until they are finally combined with oxygen and hydrogen to form water. The energy in the electrons is used to convert ADP to ATP.

The glycerol from triglyceride breakdown can also be used to produce ATP or to make glucose via gluconeogenesis. Glycerol makes up only a small proportion of the carbon in a triglyceride molecule, so the amount of glucose or ATP that can result from triglyceride breakdown is small.

How Fat Is Stored and Retrieved

Throughout the day, triglycerides are continuously stored and then broken down, depending on the immediate energy needs of the body. For example, after a meal some triglycerides will be

FIGURE 5.14 Providing energy from triglycerides
The breakdown of triglycerides yields fatty acids and a small amount of glycerol. Fatty acids provide most of the energy stored in a triglyceride molecule.



1. Fatty acids are transported inside the mitochondria where β-oxidation splits the carbon chains into two-carbon units that form acetyl-CoA and produces high-energy electrons. β-Oxidation of palmitic acid, shown here, yields eight molecules of acetyl-CoA.
2. If oxygen and enough carbohydrate are available, acetyl-CoA combines with oxaloacetate to enter the citric acid cycle, producing two molecules of carbon dioxide and releasing high-energy electrons that are shuttled to the electron transport chain.
3. In the final step of aerobic metabolism, the energy from the high-energy electrons released from β-oxidation and the citric acid cycle pumps hydrogen ions across the inner mitochondrial membrane. As the hydrogen ions flow back, the energy is used to convert ADP to ATP. The electrons are combined with oxygen and hydrogen to form water.
4. Glycerol molecules, from triglyceride breakdown, contain three carbon atoms. They can be used to produce small amounts of ATP or form glucose.

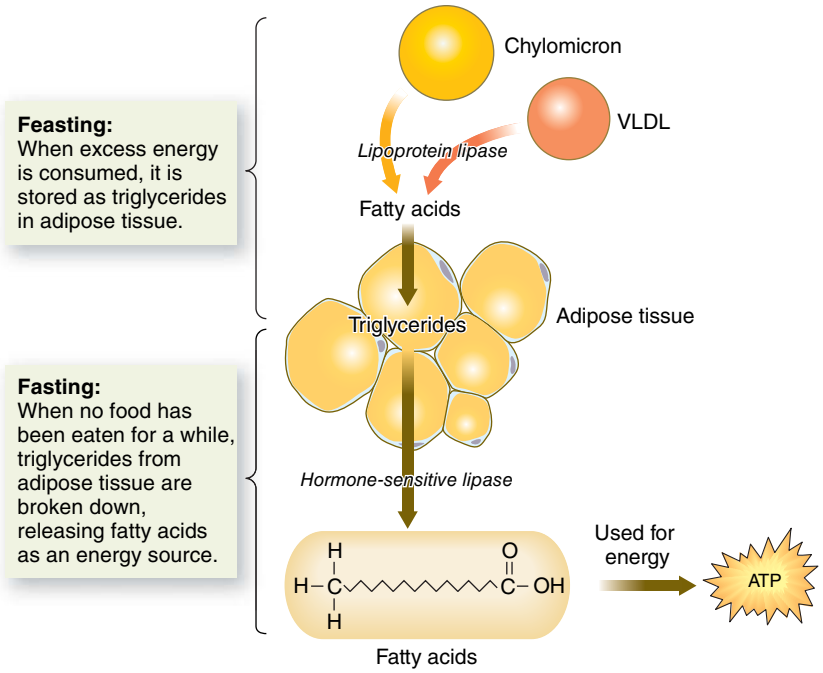


FIGURE 5.15 Fat storage during feasting and fasting
Energy is stored in or released from adipose tissue depending on body needs. The enzyme lipoprotein lipase promotes triglyceride storage; hormone-sensitive lipase stimulates the removal of triglycerides from adipose tissue.

THINK CRITICALLY
If you skip breakfast, where does your body get ATP?

stored; then, between meals, some of the stored triglycerides will be broken down to provide energy. When the energy in the diet equals the body's energy requirements, the net amount of stored triglyceride in the body does not change.

Feasting When energy is ingested in excess of needs, the excess can be stored as fat in adipose tissue. Excess energy consumed as fat is packaged in chylomicrons and transported directly from the intestines to the adipose tissue. Because the fatty acids in our body fat come from the fatty acids we eat, what we eat affects the fatty acid composition of our adipose tissue; therefore, if you eat more saturated fat, there will be more saturated fat in your adipose tissue.

Excess energy consumed as carbohydrate or protein must first go to the liver, where the carbohydrate and protein can be used, although inefficiently, to synthesize fatty acids; these fatty acids are then assembled into triglycerides, which are transported to the adipose tissue in VLDLs. Lipoprotein lipase at the membrane of cells lining the blood vessels breaks down the triglycerides from both chylomicrons and VLDLs so that the fatty acids can enter the cells, where they are reassembled into triglycerides for storage (Figure 5.15).

The ability of the body to store fat is theoretically limitless. Adipocytes can increase in weight by about 50 times, and new adipocytes can be synthesized when existing cells reach their maximum size (see Chapter 7). Because each gram of fat provides 9 kcal, compared with only 4 kcal/g from carbohydrate or protein, a large amount of energy can be stored in the body as fat without a great increase in size or weight. Even a lean man, whose body fat is only about 10% of his weight, stores over 50,000 kcal of energy as fat.

Fasting When less energy is consumed than is needed, the body uses energy from fat stores. In this situation, the enzyme **hormone-sensitive lipase** inside the adipocytes receives a hormonal signal that turns on enzyme activity. The enzyme then begins to break down stored triglycerides (see Figure 5.15). The fatty acids and glycerol are released directly into the blood, where they can be taken up by cells throughout the body to produce ATP.

hormone-sensitive lipase
An enzyme present in adipocytes that responds to chemical signals by breaking down triglycerides into fatty acids and glycerol for release into the bloodstream.

If there is not enough carbohydrate to allow acetyl-CoA from fat breakdown to enter the citric acid cycle, the acetyl-CoA will be used to make ketones (see Figure 4.16). Ketones can be used as an energy source by muscle and adipose tissue. During prolonged starvation, the brain can adapt to use ketones to meet about half of its energy needs. For the other half, it must use glucose. Fatty acids cannot be used to make glucose, and, as seen in Figure 5.14, only a small amount of glucose can be made from glycerol.

5.6 Lipids and Health

LEARNING OBJECTIVES

- Describe the events that lead to the development of atherosclerosis.
- Evaluate your risk of heart disease.
- Discuss the relationship between dietary fat and cancer.
- Explain how dietary fat intake is related to obesity.

The amount and types of fat you eat can affect your health. A diet that is too low in fat can reduce the absorption of fat-soluble vitamins, slow growth, and impair the functioning of the skin, eyes, liver, and other body organs. Eating the wrong types of fat can increase the risk of developing chronic diseases such as **cardiovascular disease** and cancer. Consuming too much fat can increase energy intake and contribute to extra body fat storage and therefore weight gain. Excess body fat, in turn, is associated with an increased risk of type 2 diabetes, cardiovascular disease, and high blood pressure.

cardiovascular disease Any disease affecting the heart and blood vessels.

Cardiovascular Disease

An estimated 85.6 million adults in the United States suffer from one or more types of cardiovascular disease.[21] It is the number one cause of death of both men and women in the United States. **Atherosclerosis** is a type of cardiovascular disease in which lipids and fibrous material are deposited in the artery walls, reducing their elasticity and eventually blocking the flow of blood. The development of atherosclerosis has been linked to diets that are high in saturated fat and *trans* fat.[20]

atherosclerosis A type of cardiovascular disease that involves the buildup of fatty material in the artery walls.

atherosclerotic plaque The cholesterol-rich material that is deposited in the arteries of individuals with atherosclerosis. It consists of cholesterol, smooth muscle cells, fibrous tissue, and eventually calcium.

How Does Atherosclerosis Develop? Inflammation, which is the process whereby the body responds to injury, is what drives the formation of **atherosclerotic plaque**. For example, cutting yourself triggers an inflammatory response. White blood cells, which are part of the immune system, rush to the injured area, blood clots form, and new tissue grows to heal the wound. Similar inflammatory responses occur when an artery is injured, but instead of resulting in healing, they lead to the development of atherosclerotic plaque (Figure 5.16).

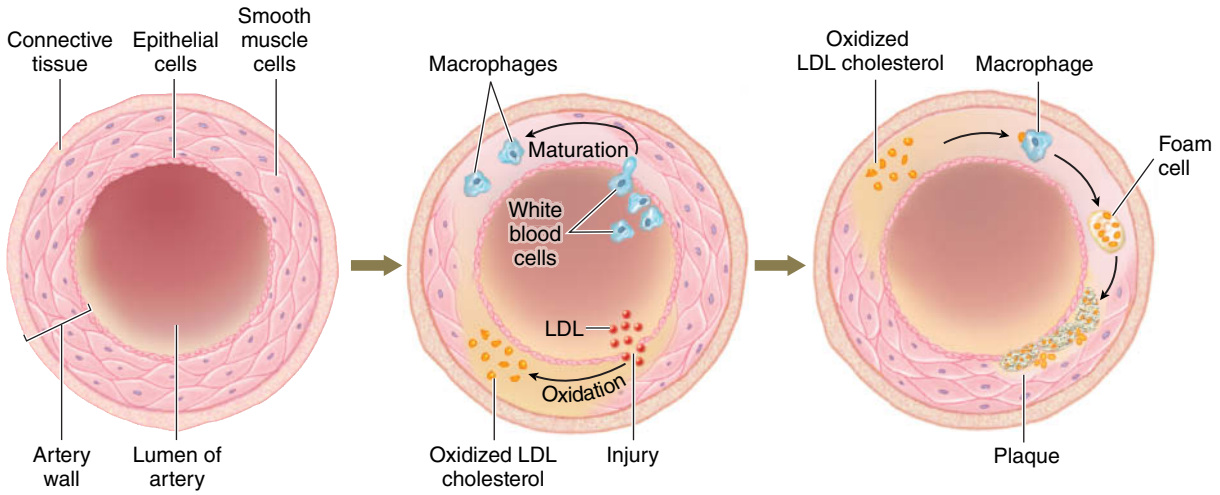
The atherosclerotic process begins as a response to an injury that causes changes in the lining of the artery wall.[22] The exact cause of the injury is not known but may be related to elevated blood levels of LDL cholesterol, glucose, or the amino acid homocysteine; high blood pressure; free radicals caused by cigarette smoking; diabetes; genetic alterations; or infectious microorganisms. The specific cause may be different in different people.

Once the initial injury has occurred, the lining of the artery becomes more permeable to LDL particles, which migrate into the artery wall (see Figure 5.16). Once inside, the LDL particles are modified chemically, often by oxidation, to form **oxidized LDL cholesterol**. Oxidized LDL cholesterol is harmful, and its presence promotes inflammation in a number of ways. It triggers the production and release of substances that cause immune system cells to stick to the lining of the artery and then to migrate into the artery wall. Once inside, these cells become large white blood cells called *macrophages*, which have **scavenger receptors** on their surface. Just as LDL receptors bind to LDL cholesterol, scavenger receptors bind to and transport oxidized LDL cholesterol into the interior of the cell. As macrophages fill with more and more oxidized LDL cholesterol, they are transformed into cholesterol-filled foam cells (named because of their foamy appearance under a microscope). Foam cells accumulate in the artery wall and then burst, depositing cholesterol to form a fatty streak (see Figure 5.16).[22]

oxidized LDL cholesterol A substance formed when the cholesterol in LDL particles is oxidized by reactive oxygen molecules. It is key in the development of atherosclerosis because it contributes to the inflammatory process.

scavenger receptor A protein on the surface of macrophages that binds to oxidized LDL cholesterol and allows it to be taken up by the cell.

Macrophages and foam cells secrete growth factors and other chemicals that continue the inflammatory response and promote growth of the plaque. The release of growth factors signals smooth muscle cells from the wall of the artery to migrate into the fatty streak and secrete fibrous proteins. Platelets, which are cell fragments involved in blood clotting, become sticky and clump together around the lesion. As the lesion enlarges it causes the artery to narrow and lose its elasticity, hampering blood flow. As the process progresses, a fibrous cap of smooth muscle cells and fibrous proteins forms over the mixture of white blood cells, lipids, and debris, walling it off from the lumen of the artery. The formation of the cap is a way of healing the injury, but if the inflammation continues, substances secreted by immune system cells can degrade this



1 Normal Artery

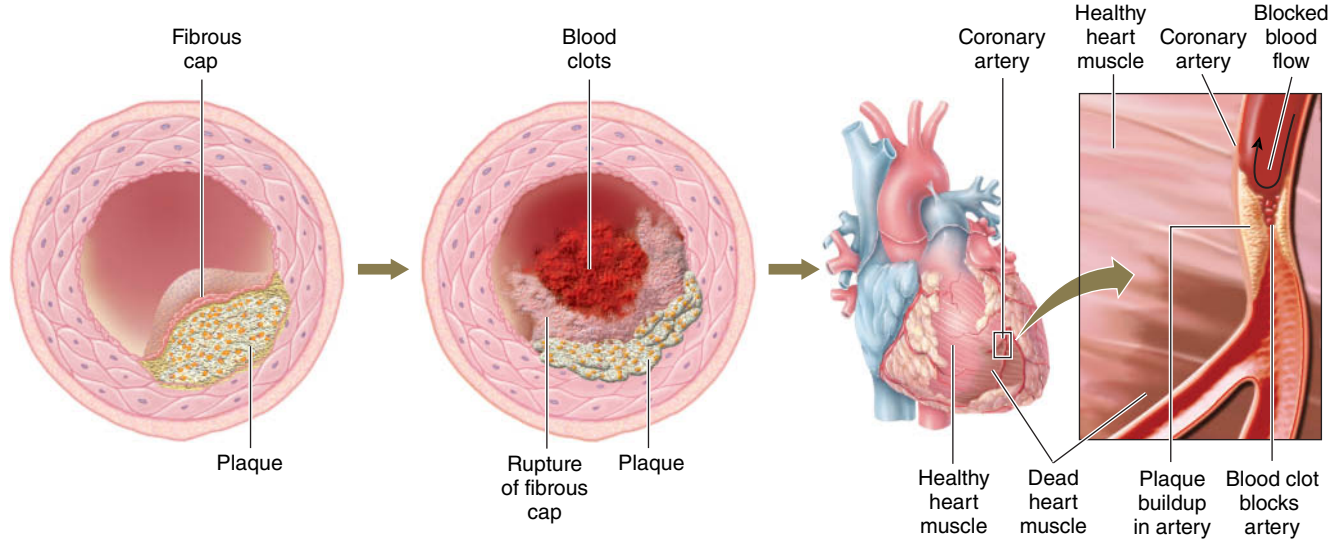
The wall of a normal, healthy artery is lined with a layer of epithelial cells that are surrounded by smooth muscle.

2 Damaged Artery

Damage to the lining of an artery causes inflammation and begins the process of plaque formation. The injury attracts white blood cells, which mature into macrophages, and makes the lining more permeable to LDL particles. Inside the artery wall, LDL is oxidized to form oxidized LDL cholesterol.

3 Plaque Formation

Inside the artery wall, macrophages fill up with oxidized LDL cholesterol and are transformed into foam cells. These cells get so full that they burst, depositing cholesterol. The accumulation of cholesterol and proteins forms a plaque.



4 Plaque Enlargement

As inflammation continues, plaque builds up, causing the artery to narrow and lose its elasticity. A cap of smooth muscle cells and fibrous proteins forms over the plaque, walling it off from the lumen of the artery.

5 Plaque Rupture

If the inflammation continues, the fibrous cap covering the plaque degrades. If the cap ruptures or erodes, blood clots can rapidly form around it. The blood clots can completely block the artery at that spot or break loose and block an artery elsewhere.

6 Heart Attack

If blood flow in a coronary artery is blocked, a heart attack results. Heart muscle cells are cut off from their blood supply and die, causing pain and reducing the heart's ability to pump blood.

FIGURE 5.16 Development of atherosclerosis
The inflammation that occurs in response to an injury to the artery wall precipitates the development of atherosclerotic plaque. The buildup of plaque can eventually lead to a heart attack or stroke.

cap. If the cap becomes too thin and ruptures, the material leaks out and causes blood clots to form.[23] The clots can completely block the artery at that spot, or break loose and block an artery elsewhere. If this occurs in blood vessels that supply the heart muscle, blood flow to the heart muscle is interrupted and heart cells die, resulting in a heart attack or myocardial infarction (see Figure 5.16). If blood flow to the brain is interrupted, a stroke results.

Risk Factors for Heart Disease High blood pressure, diabetes, obesity, and abnormal blood lipid levels are considered primary risk factors because they directly increase the risk of developing heart disease (Table 5.1). Other factors that affect risk include age,

THINK CRITICALLY

Which of the risk factors in the table are modifiable?

TABLE 5.1 What Affects the Risk of Heart Disease?

Risk factor	How it affects risk
Age	The risk of heart disease is increased in men ages 45 and older and in women ages 55 and older. About half of people with cardiovascular disease are 60 or older.[21]
Gender	Men and women are both at risk for heart disease, but men are generally affected a decade earlier than are women. This difference is due in part to the protective effect of the hormone estrogen in women. As women age, the effects of menopause—including a decline in estrogen level and a gain in weight—increase heart disease risk. Although we tend to think of heart disease as a man's disease, cardiovascular disease has claimed the lives of more women than men in every year since 1984.[21]
Genetic background	Individuals with a male family member who exhibited heart disease before age 55 or a female family member who exhibited heart disease before age 65 are considered to be at increased risk. African Americans have a higher risk of heart disease than the general population, in part due to their higher incidence of high blood pressure.[21]
High blood pressure (blood pressure ≥ 140/90 mm Hg)	High blood pressure can damage blood vessel walls, contributing to atherosclerosis. It forces the heart to work harder, causing it to enlarge and weaken over time.[20]
Diabetes (fasting blood glucose ≥ 126 mg/100 mL)	Diabetes is an independent risk factor for heart disease. The risk of a heart attack in individuals with diabetes is almost twice that of those without diabetes. High blood glucose damages blood vessel walls, contributing to atherosclerosis.
Obesity (body mass index[a] ≥ 30)	The greater an individual's BMI, the greater his or her risk for heart disease. Obesity increases blood pressure, blood cholesterol levels, and the risk of developing diabetes. It also increases the amount of work the heart must do to pump blood throughout the body.
Blood lipid levels	High blood levels of LDL cholesterol and triglycerides and low levels of HDL cholesterol increase risk (see online Appendix F). An individual's specific goal for blood levels of LDL cholesterol depends on their other risk factors for heart disease. Cholesterol-lowering medications, called *statins*, are recommended for individuals with a high overall risk.[16]
Tobacco use	Tobacco use increases the risk of heart disease by itself. It also increases blood pressure, decreases exercise tolerance, and increases the tendency for blood to clot.
Physical activity	Regular physical activity decreases risk by reducing blood pressure, lowering LDL cholesterol, increasing healthy HDL cholesterol levels, reducing the risk of diabetes, and promoting a healthy weight. Adults are advised to engage in 40 minutes of moderate to vigorous-intensity aerobic physical activity three to four times per week.[24]
Diet	A dietary pattern that emphasizes fruits, vegetables, legumes, whole grains, low-fat dairy products, poultry, fish, and nuts and that limits red meat and sugary foods and beverages reduces the risk of heart disease. Risk is further reduced by minimizing *trans* fat intake and keeping saturated fat to 5 to 6% of calories while increasing fiber and moderating calories to keep weight in the healthy range.[24]

[a]See Chapter 7 for information on body mass index (BMI) and how it can be calculated.

© Jeff Greenberg/Age Fotostock America, Inc.

FIGURE 5.17 Get your blood cholesterol checked
Getting your total and HDL blood cholesterol checked is just part of understanding your overall risk of heart disease. Smoking or having high blood pressure, diabetes, obesity, or a family history of heart disease also contributes to your risk. To estimate your 10-year risk of having a heart attack, go to the National Heart, Lung, and Blood Institute's *Risk Assessment Tool for Estimating Your 10-year Risk of Having a Heart Attack* at http://cvdrisk.nhlbi.nih.gov/calculator.asp.

gender, genetic background, and lifestyle factors such as tobacco use, physical activity, and diet. These may directly affect risk or act indirectly by altering blood lipid levels, blood pressure, body weight, or the risk of diabetes. While you can't change your gender, age, or genetic makeup, you can monitor risk factors and modify your lifestyle to reduce your risk (**Figure 5.17**).

How Diet Affects the Risk of Heart Disease Evidence suggests that diets that are rich in whole grains, fruits, vegetables, and legumes; include nuts, fish, and low-fat dairy products; and are limited in sodium, saturated fat, *trans* fat, refined grains, and sugar-sweetened foods and beverages can reduce the risk of heart disease (**Figure 5.18**).[25,33] The USDA Food Patterns and their vegetarian adaptations, the DASH diet (see Chapter 10), and the Mediterranean diet all promote this type of food and nutrient pattern. In contrast, diets high in added sugars, saturated fat, and sodium, can increase risk by contributing to the development of high blood lipid levels or high blood pressure. Excess energy can also increase the risk of heart disease by contributing to obesity (see Chapter 7).

Much of the impact that a dietary pattern has on heart disease risk depends on the abundance of nutrients and other dietary components that affect blood cholesterol levels (see Figure 5.18). For example, saturated fatty acids from high-fat meats and whole-fat dairy products can cause an increase in blood levels of total and LDL cholesterol and thereby increase the risk of heart disease. Soluble fibers and plant sterols reduce risk by lowering blood cholesterol. Replacing foods that are high in cholesterol-raising fats with foods that provide omega-3 fatty acids, monounsaturated fat, soluble fiber, and plant sterols, which have been shown to lower total and LDL cholesterol, can reduce the risk of heart disease. Nutrients and other dietary components can also affect heart disease risk through mechanisms unrelated to blood cholesterol level.

How Dietary Cholesterol Affects Risk The extent to which cholesterol intake affects blood levels depends on an individual's genes. Cholesterol in the blood comes from cholesterol both consumed in the diet and made by the liver. Generally, the body makes about three to four times more cholesterol than is consumed in the diet. Previously, limiting dietary cholesterol was thought to be important in maintaining normal blood cholesterol levels. However, current science suggests that in most individuals, dietary cholesterol intake has little impact on blood cholesterol levels.[20,24,33]

Individual nutrients and food components

Factors That Increase Risk	Factors That Reduce Risk
Saturated fat	Polyunsaturated fat
Trans fat	Monosaturated fat
Sodium	Fiber
Excess sugar	B vitamins
Excess energy	Antioxidants
Excess alcohol	Moderate alcohol

Nutrients are found in foods.

Whole foods

© hlphoto/Stockphoto

Fish is high in omega-3 fatty acids, which reduce the risk of heart disease and decrease mortality due to heart attacks. In addition to lowering LDL cholesterol and triglyceride levels, omega-3 fatty acids protect against heart disease by decreasing blood clotting, lowering blood pressure, improving the function of the cells lining blood vessels, reducing inflammation, and modulating heartbeats.[26]

Whole foods

© Donald Erickson/iStockphoto

Nuts are a good source of monounsaturated fat, which lowers LDL cholesterol and makes it less susceptible to oxidation. Nuts are also high in omega-3 fatty acids, fiber, vegetable protein, antioxidants, and plant sterols. Diets containing nuts may improve blood lipids and the functioning of cells lining the artery wall.[27]

Whole foods

© SvetI/iStockphoto

Oatmeal and brown rice are good sources of soluble fiber, which has been shown to reduce blood cholesterol levels. Whole grains also provide omega-3 fatty acids, B vitamins, and antioxidants, as well as phytochemicals that may protect against heart disease.[28]

Whole foods

© Pierre-Luc Bernier/iStockphoto

Modest consumption of dark chocolate is associated with reduced risk of heart disease. This effect is attributed to the phytochemicals in dark chocolate.[30] In addition, most of the fat in chocolate is from stearic acid, a saturated fatty acid that does not cause an increase in blood levels of LDL cholesterol.

Whole foods

Photo Researchers, Inc.

Plant sterols resemble cholesterol chemically, making it difficult for the digestive tract to distinguish them from cholesterol. Consuming plant sterols reduces cholesterol absorption in the small intestine, lowering total and LDL cholesterol levels.[32] Plant sterols are found in vegetable oils, nuts, seeds, cereals, legumes, and many fruits and vegetables and are added to special margarines, salad dressings, and orange juice.

FIGURE 5.18 Dietary patterns affect heart disease risk
Combinations of nutrients and whole foods make up dietary patterns. Our dietary pattern, often referred to as the total diet, has a greater impact on the risk of heart disease, than the individual foods and nutrients we consume.

Why Saturated Fat Increases Risk When the diet is high in saturated fatty acids, liver production of cholesterol-carrying lipoproteins increases and the activity of LDL receptors in the liver is reduced, so that LDL cholesterol cannot be removed from the blood.[34] Therefore, diets high in saturated fat increase LDL cholesterol in the blood.[35] Increased LDL cholesterol then increases the risk of atherosclerosis. When the diet is low in saturated fat, lipoprotein production decreases and the number of LDL receptors increases, allowing more cholesterol to be removed from the bloodstream. This lowers LDL cholesterol levels and the risk of heart disease. However, not all saturated fatty acids have an adverse effect on blood lipid levels. For example, the saturated fatty acid stearic acid, which makes up about half the saturated fatty acids in cocoa butter and about a third in beef fat, does not affect blood LDL, HDL, or triglyceride levels.[36] Lauric acid, which is found in the tropical oils, increases total cholesterol, but also increases healthy HDL cholesterol (see **Debate: Coconut Oil: Does a Tablespoon a Day Keep the Doctor Away?**).[37–39]

How *Trans* Fat Increases Risk Both clinical and epidemiological studies provide evidence that a high *trans* fatty acid intake increases the risk of heart disease. Many studies

Whole foods

© Florea Marius Catalin/iStockphoto

Moderate alcohol consumption—that is, one drink a day for women and two a day for men (one drink is equivalent to 5 ounces [oz] of wine, 12 oz of beer, or 1.5 oz of distilled spirits)—reduces blood clotting and increases HDL cholesterol.[29] Higher alcohol intake increases the risk of heart disease and causes other health and societal problems.

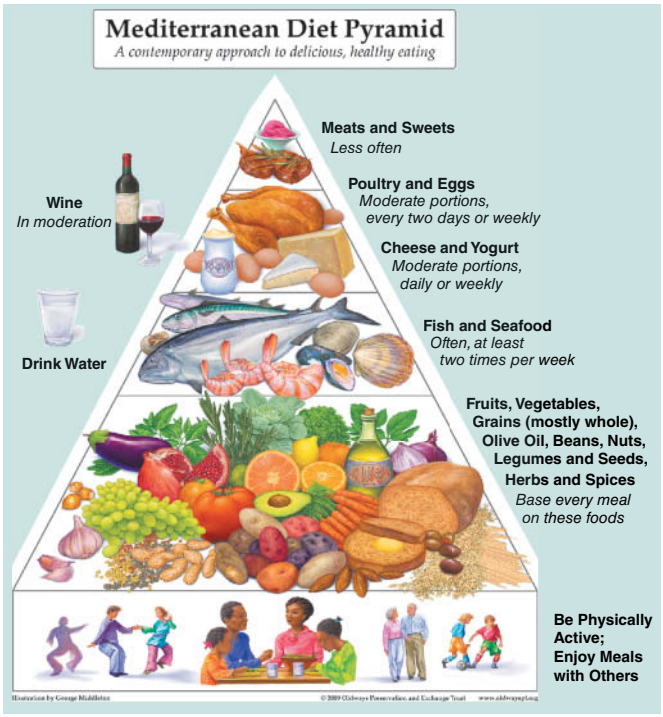
Whole foods

© Igor Dutina/iStockphoto

Soy-based diets are associated with a lower risk of heart disease. Soy has a small LDL cholesterol-lowering effect, but it may have anti-inflammatory properties that help lower the risk of heart disease.[31]

Foods make up dietary patterns.

Dietary patterns



©2009 Oldways Preservation & Exchange Trust, www.oldwayspt.org

In the Mediterranean region, the main source of dietary fat is olive oil, and the typical diet is high in nuts, legumes, vegetables, and fruits. Fish is consumed routinely and red meat rarely. Despite a fat intake that is similar to that of the U.S. diet, the incidence of heart disease is much lower. This diet pyramid is based on the dietary patterns of Crete, Greece, and southern Italy around 1960, when the rates of chronic disease in this region were among the lowest in the world. The Mediterranean diet is one of many dietary patterns that promotes heart health.

have found that diets high in *trans* fatty acids cause a greater increase in heart disease risk than those high in saturated fatty acids.[47] A 2% increase in energy intake from *trans* fat, the equivalent of adding 4 g of *trans* fat to a 2000-kcal diet, was associated with a 23% increase in cardiovascular risk.[48] *Trans* fatty acids increase risk by raising LDL cholesterol levels, lowering HDL cholesterol, increasing inflammation, and adversely affecting how blood vessels function.[47]

How Polyunsaturated Fat Reduces Risk When saturated fat in the diet is replaced by any type of polyunsaturated fat (except *trans*), blood levels of LDL cholesterol decrease.[25] However, a high intake of omega-6 polyunsaturated fatty acids may also cause a slight decrease in HDL cholesterol, which is undesirable in terms of heart disease risk. Diets high in linoleic acid, the predominant dietary omega-6 fatty acid, are associated with a lower risk of heart disease and a lower risk of death from heart disease.[49] Increasing omega-3 fatty acid intake also lowers levels of LDL cholesterol but not HDL cholesterol. Omega-3 fatty acids may also reduce heart disease risk by

DEBATE

Coconut Oil: Does a Tablespoon a Day Keep the Doctor Away?

Claims abound that coconut oil can protect you from heart disease and help you lose weight. You can add it to your coffee, put it in your smoothie, bake it into goodies, or just use it for frying. But adding fat adds calories, and coconut oil, one of the tropical oils, is high in saturated fat. So, why is it being sold to improve your health?

Coconut oil, like any oil, provides 9 kcal/g; a tablespoon provides about 120 kcal. But coconut oil is unusual because it contains a high percentage of medium-chain triglycerides (MCTs). Most oils are made up of long-chain triglycerides (LCTs). Our bodies metabolize MCTs differently than LCTs. Instead of being incorporated into chylomicrons, MCTs are transported directly from the intestines to the liver, where they can be broken down to provide ATP. Coconut oil is also high in lauric acid, a 12-carbon saturated fatty acid. Lauric acid raises blood levels of total cholesterol but unlike other saturated fatty acids, it also raises levels of healthy HDL cholesterol.[40]

So, does this mean that a diet high in coconut oil is good for your heart? Unfortunately, data on the effect of coconut oil on heart disease are scarce. We know that the incidence of heart disease is not elevated in Polynesian islands where coconut fat intake is high, but this does not mean that the reason is coconut oil. The data on coconut oil and blood lipid levels are mixed. Filipino women with the highest coconut oil intake were found to have higher HDL levels.[41] A study that compared low-calorie diets supplemented with coconut oil versus soybean oil found an increase in HDL cholesterol in the coconut oil group.[42] But, another study showed that coconut oil caused an increase in bad LDL cholesterol as well as good HDL cholesterol when compared to olive oil.[43]

What about weight loss? MCT oil is less likely to be stored in adipose tissue. Does this mean that adding coconut oil will make weight loss easier? A study that compared obese subjects who consumed 18 g of MCT oil as part of their daily diet with subjects consuming 18 g of corn oil found that the MCT oil group lost weight and decreased their waist circumference.[44] A study that looked at MCT oil versus olive oil as part of a low-calorie diet showed greater weight loss in the MCT oil group, but the difference was small.[45] Another study that compared food intake after a premeal dose of MCT oil versus LCT oil showed a reduction in food and calorie intake in the MCT group.[46] These studies suggest that MCT oil may promote weight loss, but they were done using 100% MCT. Coconut oil is only 60% MCT. It is unclear whether coconut oil would have a similar effect. One study that compared coconut versus soy oils in addition to a low-calorie diet showed similar weight loss in both groups, but a greater reduction in waist circumference in the coconut oil group.[42]

mypokcik/Shutterstock

Coconut oil contains an unusual blend of fatty acids that may have health benefits.

Coconut oil is gaining favor. Vegans are using it as a plant-based alternative to butter on their toast and chefs are discovering its unique properties in food. But is adding coconut oil likely to improve your health? Adding it to your diet may give you a slight weight loss edge but only if you make room by eating less of something else.

THINK CRITICALLY: Will adding coconut oil to a dietary pattern that doesn't meet health recommendations make it a healthy diet?

improving blood pressure, cardiac function, blood clotting, and immunological and inflammatory processes.[50]

Populations that consume a diet high in omega-3 fatty acids from seafood, such as the Inuits in Greenland, have a low incidence of heart disease, despite a high intake of total fat.[51,52]

How Monounsaturated Fat Reduces Risk As with polyunsaturated fatty acids, substituting monounsaturated fat for saturated fat reduces blood levels of unhealthy LDL cholesterol. However, because fewer double bonds are present in monounsaturated fatty acids, they are less susceptible

to oxidation than polyunsaturated fatty acids. Therefore, dietary monounsaturated fatty acids decrease the oxidative susceptibility of LDL compared to polyunsaturated fatty acids. So monounsaturated fatty acids will reduce the formation of oxidized LDL, which is known to induce an inflammatory response and stimulate production of other reactive oxygen species, processes that contribute to the progression of atherosclerosis.[53]

VIDEO

Diets high in monounsaturated fatty acids are associated with a lower risk of heart disease and stroke.[54] Populations with diets high in monounsaturated fats, such as those in Mediterranean countries where olive oil is commonly used, have a mortality rate from heart disease that is half of that in the United States. This is true even when total fat intake provides 40% or more of energy intake.[55] However, the high intake of monounsaturated fat from olive oil is unlikely to be the only factor responsible for the difference in the incidence of heart disease between the Mediterranean countries and the United States. The typical Mediterranean diet is higher in fruits and vegetables and lower in animal products than the current U.S. diet, and is consumed in countries where the lifestyle includes more day-to-day activity and has fewer of the stresses of modern life (see Figure 5.18).

Why Plant Foods Reduce Risk Dietary patterns that include higher intakes of plant foods are associated with a lower incidence of cardiovascular disease.[56] The reason may be that many of the dietary components that protect you from heart disease and few of those that increase risk are found in plant foods. Fruits, vegetables, whole grains, nuts, seeds, and legumes are good sources of fiber, omega-3 fatty acids (α-linolenic acid), antioxidant vitamins, and phytochemicals. Soluble fibers, such as those in oat bran, legumes, psyllium, and flaxseed, have been shown to reduce blood cholesterol levels and therefore reduce heart disease risk (see Chapter 4). The antioxidant vitamins and phytochemicals in plant foods protect against heart disease because they decrease the oxidation of LDL cholesterol and therefore are hypothesized to prevent development of plaque in artery walls.[57]

Why B Vitamins Reduce Risk Adequate intakes of vitamin B_6, vitamin B_{12}, and folic acid can help protect against heart disease because they keep blood levels of the amino acid homocysteine low (see Chapter 8). Elevated homocysteine levels are associated with a higher incidence of heart disease.[58] The fortification of enriched grains with folic acid in 1998 increased folic acid intake in the United States and Canada and has resulted in a reduction in blood homocysteine levels and the risk of stroke in these populations.[59] The evidence that supplements of B vitamins help prevent heart disease is currently not strong enough to recommend them to reduce the risk of heart disease and stroke.[58,60]

Niacin is another B vitamin that may affect heart disease risk. When consumed in extremely high doses, the nicotinic acid form of niacin can be used to lower blood cholesterol. Nicotinic acid is inexpensive and widely available without a prescription, but at the high doses needed to lower cholesterol it should be considered a drug, not a nutrient. Because of the potential side effects, an individual using nicotinic acid as a drug to lower cholesterol should be monitored by a physician.

Moderate Alcohol Consumption Alcohol can be a dangerous drug, but moderate alcohol consumption has been shown to reduce stress, to raise levels of HDL cholesterol, and to reduce blood clotting and thus reduce the risk of cardiovascular disease.[29,61] These effects are greater when red wine is consumed, as it commonly is in Mediterranean countries (see Figure 5.18). Red wine is high in phytochemicals called *polyphenols*, which are antioxidants that protect against LDL oxidation, and may have other effects that protect against the development of atherosclerosis[61] (see Focus on Alcohol).

Dietary Fat and Cancer

Cancer is the second leading cause of death in the United States. As with cardiovascular disease, there is evidence that the risk of cancer can be reduced with changes in diet and activity patterns.[62] Populations consuming diets high in fruits and vegetables tend to have a lower cancer risk. These foods are high in fiber and provide antioxidant vitamins and phytochemicals. In contrast, populations that consume diets high in fat, particularly animal fats, have a higher cancer incidence.

Cancer involves a breakdown in cells' regulatory systems (as discussed in Chapter 4) resulting in rapid uncontrolled growth and spread of cancer cells. Animal models for cancer and human cancer cells grown in culture demonstrate that certain types of fatty acids are associated with the growth and development of cancer cells.[63] Fatty acids have the potential to affect cancer development through their role in eicosanoid synthesis and membrane metabolism. Changes in the ratio of omega-6 to omega-3 fatty acids in the diet can affect membrane structure, function, cellular oxidative status, and the activity of enzymes and cell signaling pathways.[63]

The good news is that for the most part the same type of diet that protects you from cardiovascular disease will also reduce the risk of certain forms of cancer. For example, the Mediterranean diet, which is high in monounsaturated fat from olive oil and omega-3 fatty acids from fish, is associated with a low risk of cancers of the breast, colon, prostate, and upper digestive and respiratory tracts.[64,65] *Trans* fatty acids, on the other hand, not only increase the risk of heart disease but are also believed to increase mortality from breast cancer.[66]

Dietary Fat and Obesity

Dietary fat has been postulated to contribute to weight gain and obesity. One reason is that fat has 9 kcal/g, more than twice as much as either carbohydrate or protein. Therefore, a high-fat meal contains more calories in the same volume as a lower-fat meal. Because people have a tendency to eat a certain weight or volume of food, a high-fat meal will add more calories than a lower-fat meal.[67,68] High-fat diets also tend to promote overconsumption because energy from fat is less satiating than energy from protein, so when eating a high-fat meal you will eat more calories before you feel full. Dietary fat may also contribute to weight gain because it is stored very efficiently as body fat (see Chapter 7). Overall, as the fat content of the diet increases, so does the calorie intake.[69]

Despite the fact that fat is fattening, the fat content of the U.S. diet is unlikely to be the sole reason for the high rate of obesity in the United States.[70] Weight gain occurs when energy intake exceeds energy expenditure, regardless of whether the extra energy comes from fat, carbohydrate, or protein. The increasing prevalence of overweight and obesity in the United States and worldwide is likely due to a general increase in calorie intake combined with a decrease in energy expenditure.[20]

5.7 Meeting Recommendations for Fat Intake

LEARNING OBJECTIVES

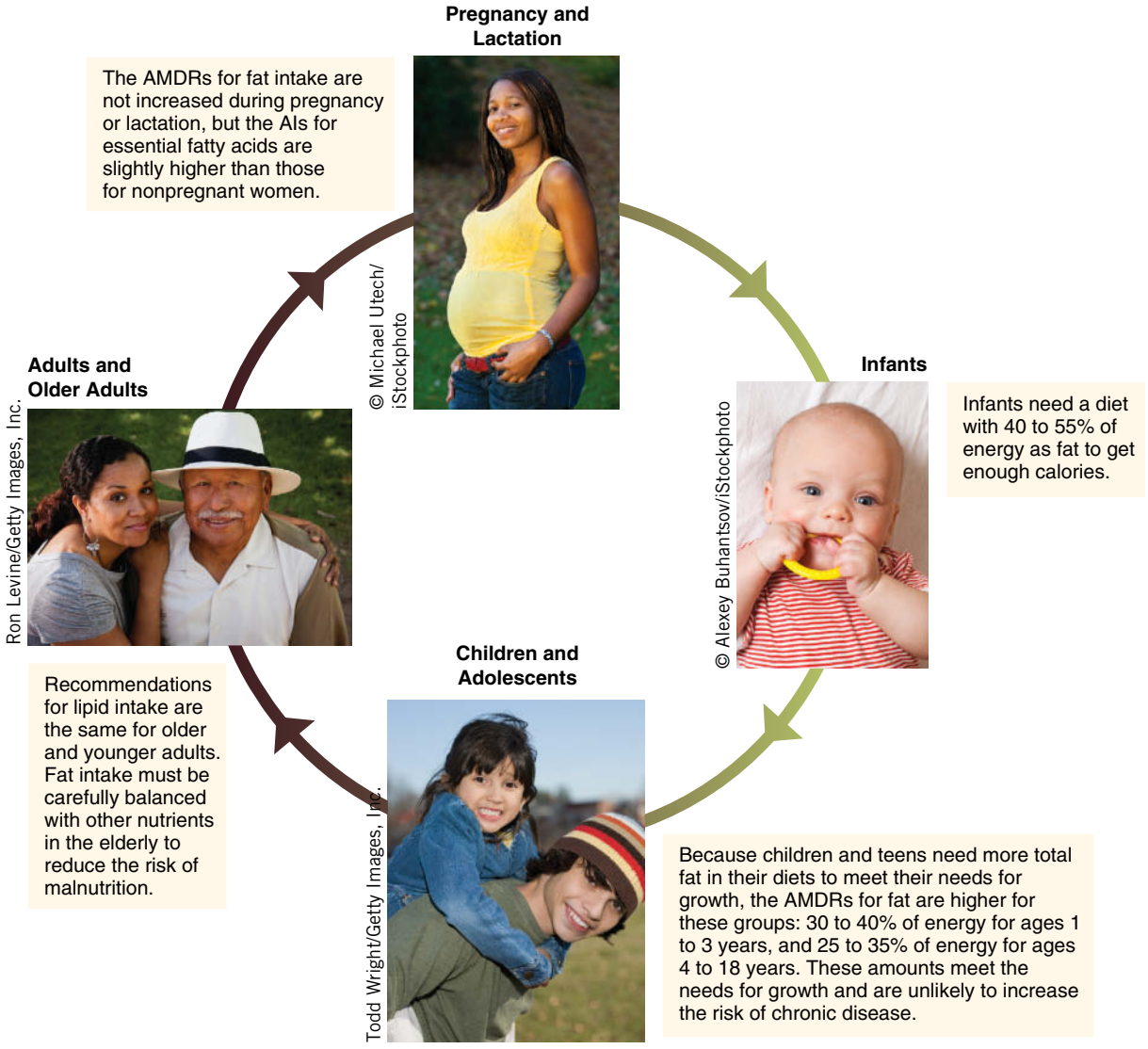
- Discuss the recommendations for fat and cholesterol intake.
- Choose heart-healthy foods from each section of MyPlate.
- Use food labels to choose foods that provide healthy fats.

Recommendations for fat intake focus on getting enough to meet the need for essential fatty acids and choosing a diet that provides the amounts and types of fat that will promote health and prevent disease. Following the Dietary Guidelines and MyPlate and using the information on food labels can help translate these recommendations into appropriate food choices and overall healthy diets.

Fat and Cholesterol Recommendations

Only a small amount of fat is required for life, but a diet that provides only the minimum amount would be very high in carbohydrate, would not be very palatable, and would not necessarily be any healthier than diets with more fat. Recommendations for healthy amounts and types of fat are made by the DRIs and the Dietary Guidelines as well as organizations and programs that target specific diet-related chronic diseases such as heart disease and cancer.

FIGURE 5.19 Lipid recommendations throughout the life cycle



Essential Fatty Acid Needs The amounts of the essential fatty acids recommended by the DRIs are based on the amounts consumed by the healthy U.S. population. The AI for linoleic acid is 12 g/day for women and 17 g/day for men. You can meet your requirement by consuming a half-cup of almonds or 2 tablespoons of corn oil. For α-linolenic acid, the AI is 1.1 g/day for women and 1.6 g/day for men. Your requirement can be met by eating a quarter-cup of walnuts or a tablespoon of ground flaxseeds. Consuming these amounts provides the recommended ratio of linoleic to α-linolenic acid of between 5:1 and 10:1.[5] AMDRs of 5 to 10% of energy for linoleic acid and 0.6 to 1.2% of energy for α-linolenic acid (with 10% or less of this as EPA and DHA) have been set.[5]

How Much Total Fat? The DRIs set an AMDR for total fat intake of 20 to 35% of calories for adults, allowing a range of fat intakes to meet individual food preferences while still promoting health. Recommendations differ somewhat for different life stages (Figure 5.19). Fat intakes above the AMDR make it more difficult to avoid consuming excess calories. Intakes below the 20% lower level of the AMDRs increase the probability that vitamin E and essential fatty acid intakes will be low and may contribute to unfavorable changes in HDL and triglyceride levels.

TABLE 5.2 Calculating Percentage of Energy from Fat

Determine

- The total energy (kcal) intake for the day
- The grams of fat in the day's diet

Calculate energy from fat

- Fat provides 9 kcal/g
- Multiply grams of fat by 9 kcal/g

$$\text{Energy (kcal) from fat} = \text{grams fat} \times 9 \text{ kcal/g fat}$$

Calculate percentage of energy from fat

Divide energy from fat by total energy and multiply by 100 to express as a percentage

$$\text{Percentage of energy from fat} = \frac{\text{kcal from fat}}{\text{Total kcal}} \times 100$$

For example:

A diet contains 2000 kcal and 75 g of fat

$$75 \text{ g of fat} \times 9 \text{ kcal/g} = 675 \text{ kcal from fat}$$

$$\frac{675 \text{ kcal from fat}}{2000 \text{ kcal}} \times 100 = 34\% \text{ of energy (kcal) from fat}$$

TABLE 5.3 Using Choice (Exchange) Lists to Estimate Fat Content

Food groups/lists	Serving size	Fat (g)
Carbohydrate group		
Starch	⅓ cup pasta; ½ cup potatoes; 1 slice bread	0–1
Fruit	1 small apple, peach, pear; ½ banana; ½ cup canned fruit (in juice)	0
Milk	1 cup milk or yogurt	
Nonfat		0
Low-fat		2–3
Reduced-fat		5
Whole		8
Other carbohydrates	Serving sizes vary	Varies
Vegetables	½ cup cooked vegetables, 1 cup raw	0
Meat/meat substitute group	1 oz meat or cheese, ½ cup legumes	
Very lean		0–1
Lean		3
Medium-fat		5
High-fat		8
Fat group	1 tsp butter, margarine, or oil; 1 T salad dressing	5

The percentage of energy from fat in your diet can be calculated by using the equations shown in Table 5.2. This same calculation can be used to determine the percentage of energy as saturated fat in the diet, or of total fat or saturated fat in individual foods. The amount of fat in a food or in a diet can be estimated from the Choice (Exchange) Lists (Table 5.3) or determined using values from food labels, food composition tables, or iProfile or other diet analysis programs (see online *Nutrient Composition of Foods* supplement).

What Types of Lipids Are Recommended? To reduce the risk of heart disease, it is recommended that everyone over age 2 limit saturated fatty acid intake to less than 10% of total calories by replacing foods high in saturated fat with sources of mono- or polyunsaturated fat.[20] The consumption of omega-3 fatty acids should be increased to achieve a healthier ratio

HOW TO CHOOSE	The Right Fats
Limit your intake of saturated fat and *trans* fat	
• Choose low-fat milk and yogurt.	
• Trim the fat from your meat, and serve chicken and fish but don't eat the skin.	
• Cut in half your usual amount of butter and use soft rather than stick margarine.	
• Watch your fast-food choices—choose grilled chicken over burgers and skip the special sauce.	
Increase the proportion of polyunsaturated and monounsaturated fats	
• Snack on nuts and seeds.	
• Add olives and avocados to your salads.	
• Use olive, peanut, or canola oil for cooking and salad dressing.	
• Use corn, sunflower, canola, or safflower oil for baking.	
Up your omega-3 intake	
• Sprinkle ground flaxseeds on your cereal or yogurt.	
• Have a serving of mackerel, lake trout, sardines, tuna, or salmon.	
• Pick a leafy green vegetable with dinner.	
• Add walnuts to your salad or cereal.	

of omega-6 to omega-3 fatty acids. Although the Daily Values on current food labels recommend limiting cholesterol to 300 mg/day or less, the 2015–2020 Dietary Guidelines do not consider dietary cholesterol a nutrient of concern in the American diet.[20] *Trans* fat consumption should be kept as low as possible. **How to Choose: The Right Fats** gives some suggestions on how to make healthy fat choices.

Translating Recommendations into Healthy Diets

The typical U.S. diet contains the recommended amount of fat and meets essential fatty acid requirements. However, saturated fat intake often exceeds recommendations, and most people don't get enough omega-3 polyunsaturated fatty acids.[1,33] Our *trans* fat intake has declined, for the most part because food manufacturers have been replacing partially hydrogenated oils with fats that do not contain synthetic *trans* fat. In addition, the FDA has reclassified partially hydrogenated oils as food additives, which will reduce their use in foods even more.[7] Choosing a dietary pattern that is high in whole grains, fruits, vegetables, lean protein sources, including fish and nuts, and low in red meat, and solid fats will provide the recommended mix of fatty acids.

Using MyPlate to Make Healthy Choices MyPlate is designed to help you choose a healthy dietary pattern (Figure 5.20). The recommendations on fat focus on limiting solid fats from red meat, butter, and margarine and choosing liquid sources of fat from vegetable oils, fish, nuts, seeds, and avocados. This pattern will limit saturated fat and *trans* fat intake and increase the amounts of mono- and polyunsaturated fats.

Oils, butter, margarine, fatty sauces, and salad dressings used in cooking or added at the table are the most concentrated sources of fat in the diet. Limiting these can reduce your total fat and calorie intake. The MyPlate Daily Food Plans include an oils allowance. Choosing liquid oils rather than solid fats will increase the unsaturated fats and decrease the saturated fats in your diet. For example, using vegetable oils such as canola, olive, and peanut oil that are high in monounsaturated fat, or corn and soybean oils that are high in polyunsaturated fat, instead of butter will increase the proportion of unsaturated fats. Soybean oil and canola oil are also good plant sources of omega-3 unsaturated fatty acids. Limiting solid fats such as butter, beef fat, and lard will reduce saturated fat intake. Choosing soft margarines and other spreads that are low in *trans* fat can reduce *trans* fat intake.

Solid fats provide the same number of calories per gram as oils but few essential nutrients. Therefore MyPlate considers them to be empty calories. Consuming too many empty calories makes it difficult to meet your nutrient needs without gaining weight. If you consume a

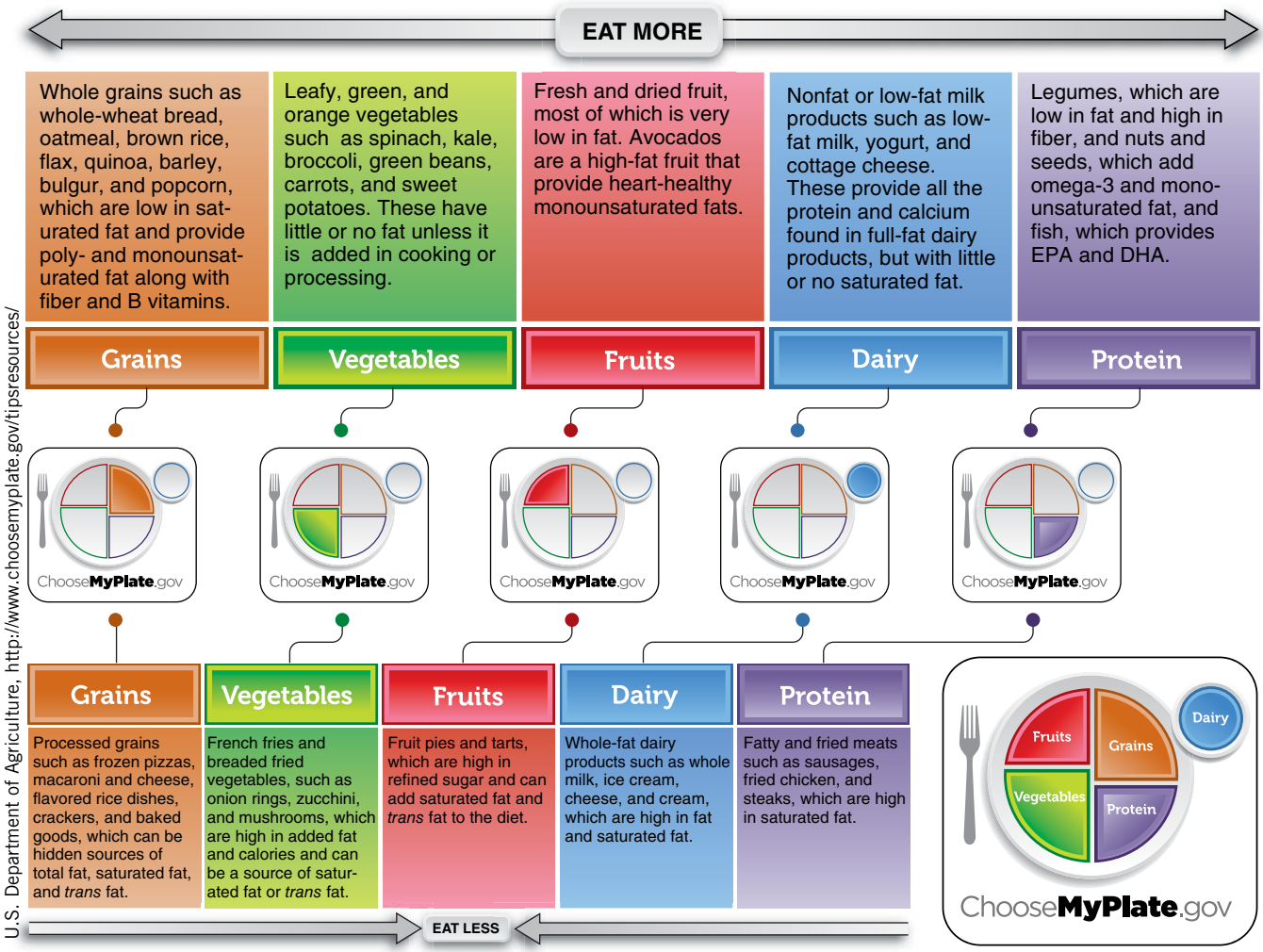


FIGURE 5.20 Healthy MyPlate choices
MyPlate recommends limiting intake of solid fats, which include fats that are high in saturated or *trans* fat, and choosing liquid oils, which are high in mono- and polyunsaturated fats.

2000-kcal diet, you can include only about 260 empty calories. Spreading 1 tablespoon of butter on your morning bagel uses up 100 kcal, more than one-third of your empty calorie allowance (see **Critical Thinking: Choosing Healthy Fats**).

Smart choices from the protein and dairy groups of MyPlate can reduce your intake of unhealthy fats and boost healthy ones. For example, limiting fatty cuts of meat and high-fat processed meats, trimming the fat from meat, removing the skin from poultry, and choosing low-fat dairy products can reduce the amount of total fat and saturated fat in the diet. Choosing legumes as a protein source provides protein with plenty of fiber and little fat of any kind. Choosing nuts, seeds, and fish from the protein group will provide monounsaturated fat and good sources of omega-3 fatty acids, which tend to be low in the American diet. Choosing more seafood is recommended because it is low in saturated fat and rich in heart-protective long-chain omega-3 fatty acids. Levels of omega-3 fatty acids are higher in oily fish such as salmon, trout, and herring. Omega-3 fatty acid supplements can help improve the ratio of omega-6 to omega-3 fatty acids, but because the beneficial effects are greater when the omega-3 fatty acids are consumed in fish as opposed to supplements, the American Heart Association recommends consuming fish twice a week to increase omega-3 intakes.[52]

Eggs are a choice from the protein group that is low in saturated fat. In the past, many people limited egg consumption because of their high cholesterol content. However, research studies indicate that dietary cholesterol does not adversely affect blood cholesterol or increase the risk of heart disease for most people.[33,71] No adverse effects were found from daily egg consumption for

CRITICAL THINKING

Choosing Healthy Fats

© Paul Johnson/iStockphoto

Isabel has a busy schedule—working full time and going to college. She picks up breakfast and lunch on the run and makes a quick dinner when she gets home at night. She would like to improve her diet by choosing healthier fats. An analysis of Isabel's fat intake is shown in the table.

FOOD	SERVING	FAT (g)	SATURATED FAT (g)	*TRANS* FAT (g)
Breakfast				
Bran muffin	1 large (3 oz)	6	2.6	0.5
Margarine, hard	2 tsp	7.6	1.4	1.4
Coffee	1 cup	0	0	0
Whole milk	1 cup	8	5	0.2
Lunch				
Big burger	1 (2 oz bun, 5 oz beef, 1 oz cheese, 2 T dressing)	30	12.5	1
French fries, small	2.5 oz	11	1.5	0.9
Diet Coke	16 oz	0	0	0
Snack				
Apple	1 med	0	0	0
Dinner				
Fish sticks	6 (3 oz)	11	2.4	0.7
Potato puffs	¾ cup	8	1.8	0.3
Hot tea	8 oz	0	0	0
Apple pie	1 slice	19	4.7	3.3
Total		**100.6**	**31.9**	**8.3**

If Isabel's diet provides 2200 kcal, what is her percentage of calories from fat? Saturated fat? Are these within the recommended range?

Which two foods contain the most saturated fat? *Trans* fat?

Fat is not the only factor in a healthy diet. Isabel compares her current diet to her MyPlate Daily Food Plan.

FOOD GROUP	DAILY FOOD PLAN	ISABEL'S DIET
Grains	7 oz (3.5 whole grains)	6 oz (3 whole)
Vegetables	3 cups	1¾ cup
Fruit	2 cups	1 cup
Dairy	3 cups	2 cups
Protein	6 oz	6 oz
Oils	6 tsp	6 tsp

CRITICAL THINKING QUESTIONS

- **Suggest a whole-grain breakfast item that has less saturated fat than the bran muffin.**
- **To increase the variety of her vegetables, suggest a more nutrient-dense vegetable to replace the potato puffs.**

CRITICAL THINKING QUESTIONS

- **Suggest a substitution that would add a fruit to Isabel's diet without increasing the calories.**
- **Isabel's weight is stable on this diet. How can she be short on fruits, vegetables, grains, and dairy, but still meet her calorie needs?**

iProfile Use iProfile to find a fast-food sandwich that has less saturated fat than a Big Mac.

OFF THE LABEL

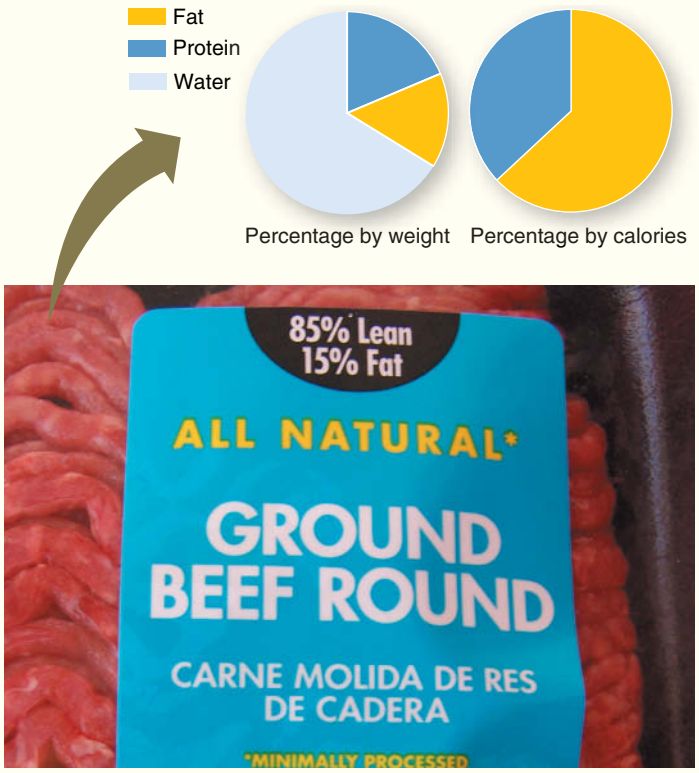
Making Sure Your Meat Is Lean

© iStockphoto

Looking for lean meat? Most fresh meats (whole cuts and ground and chopped products) are required to have a Nutrition Facts label on the package or have the equivalent nutrition information displayed nearby, but the information related to fat content can still be misleading.[73] Understanding the terminology can help you choose meats that will fit into your diet plan.

The terms "lean" and "extra lean" describe the fat content of packaged meats such as hot dogs and lunch meat, as well as fresh meats such as pork chops and steaks. "Lean" means the meat contains less than 10% fat by weight, and "extra lean" means it contains no more than 5% fat by weight. Ground beef is an exception to these labeling rules. The USDA allows ground beef to be labeled "lean" even if as much as 22% of its weight is fat. To further complicate your shopping, the amount of fat in ground beef labeled "lean" and "extra lean" can vary from store to store.

You can still figure out how much fat is in lean ground beef because ground meats labeled "lean" or "extra lean" must indicate the actual percentage of fat versus lean by stating that it is a certain "% lean" and "% fat" (see figure). So a package of ground beef like this one that is 85% lean and only 15% fat looks like a good choice. But these percentage claims can be misleading. "Percent lean" and "percent fat" refer to the weight of the meat that is lean or fat. So in a meat that is 85% lean, 85% of the weight is lean tissue and 15% of the weight of the meat is fat, so there are 15 g of fat in 100 g (3.5 oz) of raw hamburger. This is a relatively small percentage by weight, but because fat contains 9 kcal/g, the fat contributes 63% of the calories in the meat (see pie charts).



Courtesy Mary Grosvenor

Should you pass on the ground beef and select ground turkey instead? Check the label. If the package is labeled "ground turkey," it may contain skin and leg meat and actually have more fat (about 15 to 20% by weight) than lean ground beef. Only poultry labeled "ground turkey (or chicken) breast" is made with just the lean breast meat and contains only about 3% fat by weight.

THINK CRITICALLY: If you want to purchase ground beef that fits the definition of "lean" meat, what "% lean" should you look for on the label?

six weeks in healthy people, in people with elevated blood cholesterol, or in those with coronary artery disease (Figure 5.21).[33,72]

Generally, foods from the grains, fruits, and vegetables groups are low in total fat and saturated fat. However, choices from these groups need to be made with care to avoid fats that are added in processing or preparation. For example, baked goods such as doughnuts, cookies, and muffins are grain products that are sources of dietary fat. In fact, most baked goods are so high in added fats and sugars that about half of their calories are considered empty calories. Fresh vegetables are very low in fat, but French fries and breaded fried vegetables, such as onion rings and mushrooms, are high in fat and energy, and depending on the fat used for frying, can be a source of saturated fat or *trans* fat.

Using Food Labels to Make Healthy Choices Food labels provide an accessible source of information on the fat content of packaged foods and fresh meats (see **Off the Label: Making Sure**

Your Meat Is Lean). Understanding how to use this information can help you make more informed choices about the foods you include in your diet.

The Nutrition Facts section provides information about the amounts of total fat, saturated fat, *trans* fat, and cholesterol in a food (Figure 5.22). The % Daily Values for total fat and saturated fat help consumers tell at a glance how much of the recommended daily limit a serving provides. For example, if a serving provides 50% of the Daily Value for saturated fat—that is, half the recommended maximum daily intake for a 2000-kcal diet—the rest of the day's foods will have to be carefully selected to not exceed the recommended maximum. To choose foods low in total fat or saturated fat, look for foods with 5% of the Daily Value or less of these in a serving and avoid those with 20% or more. A % Daily Value for cholesterol is also found on food labels, however, the 2015–2020 Dietary Guidelines no longer stress restricting cholesterol intake.

Although the amount of *trans* fat in a serving has been included on food labels since 2006, it may mislead many consumers because products with less than 0.5 g per serving may be labeled as having 0 g of *trans* fat. As a result, individuals may ingest significant quantities of *trans* fats while believing they

© macida/iStockphoto

FIGURE 5.21 Eggs are a healthy source of protein
One large egg contains 6 g of protein and is a good source of zinc, B vitamins, vitamin A, iron, and phytochemicals. Eggs are also low in cholesterol-raising saturated fat.

FIGURE 5.22 Fat on food labels
Understanding how to use food labels can help you make more informed choices. This label, from chocolate chip cookies, tells us that they are moderately high in saturated fat and total fat, and contain less than 0.5 g of *trans* fat in a serving.

Chocolate Chip Cookies

Nutrition Facts

Serving Size 3 Cookies (33g)
Servings Per Container About 13

Amount Per Serving	
Calories 160	Calories from Fat 70
	% Daily Value*
Total Fat 8g	**12%**
Saturated Fat 3g	**15%**
Trans Fat 0g	
Polyunsat Fat 2.5g	
Monounsat Fat 2g	
Cholesterol 0mg	**0%**
Sodium 110mg	**5%**
Potassium 45mg	**1%**
Total Carbohydrate 22g	**7%**
Dietary Fiber Less than 1gram	**3%**
Sugars 11g	
Protein 2g	

Vitamin A 0% • Vitamin C 0%
Calcium 0% • Iron 4%

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Potassium	Less than	3,500mg	3,500mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

INGREDIENTS: ENRICHED FLOUR (WHEAT FLOUR, NIACIN, REDUCED IRON, THIAMINE MONONITRATE (VITAMIN B1), FOLIC ACID, SEMISWEET CHOCOLATE CHIPS (SUGAR, CHOCOLATE, COCOA BUTTER, DEXTROSE, SOY LECITHIN AN EMULSIFIER), SUGAR, SOY BEAN OIL AND/OR PARTIALLY HYDROGENATED COTTONSEED OIL, HIGH FRUCTOSE CORN SYRUP, LEAVENING (BAKING SODA AND/OR AMMONIUM PHOSPHATE), SALT, WHEY (FROM MILK), NATURAL AND ARTIFICIAL FLAVOR, CARAMEL COLOR.
CONTAINS: WHEAT, SOY, MILK

Changes proposed to the Nutrition Facts panel would eliminate *Calories from Fat.*

A % Daily Value is listed for total fat, saturated fat, and cholesterol. This allows consumers to tell how a food fits the recommendations. Generally, ≤5% of the Daily Value is low, and ≥20% is high. There are no Daily Values for *trans*, polyunsaturated, and monounsaturated fats.

The Nutrition Facts panel lists calories from fat; grams of total fat, saturated fat, and *trans* fat; and milligrams of cholesterol in a serving. The amount of monounsaturated and polyunsaturated fat is voluntarily included on the labels of some products.

If the product has less than 0.5 gram of *trans* fat per serving, the Nutrition Facts panel will list the amount of *trans* fat as 0, even if partially hydrogenated oil is an ingredient.

The Daily Values recommend consuming less than 30% of calories as fat, no more than 300 mg of cholesterol per day, and no more than 10% of calories as saturated fat. It is recommended that *trans* fat intake be limited to the amounts present naturally in meats and dairy products.

The sources of fat in a product are listed in the ingredient list with the other ingredients, in order of prominence by weight.

Andy Washnik

FIGURE 5.23 Nutrient content claims for fat and cholesterol
Food labeling regulations define the nutrient content claims used on these labels and prevent them from being used in ways that might confuse consumers.

Fat and Cholesterol Descriptors on Food Labels

Fat free	Contains less than 0.5 g of fat per serving.
Low fat	Contains 3 g or less of fat per serving.
Percent fat free	May be used only to describe foods that meet the definition of fat free or low fat.
Reduced or less fat	Contains at least 25% less fat per serving than the regular or reference product.
Saturated fat free	Contains less than 0.5 g of saturated fat per serving and less than 0.5 g *trans* fatty acids per serving.
Low saturated fat	Contains 1 g or less of saturated fat and not more than 15% of calories from saturated fat per serving.
Reduced or less saturated fat	Contains at least 25% less saturated fat than the regular or reference product.
Cholesterol free	Contains less than 2 mg of cholesterol and 2 g or less of saturated fat per serving.
Low cholesterol	Contains 20 mg or less of cholesterol and 2 g or less of saturated fat per serving.
Reduced or less cholesterol	Contains at least 25% less cholesterol than the regular or reference product and 2 g or less of saturated fat per serving.
Lean	Contains less than 10 g of fat, 4.5 g or less of saturated fat, and less than 95 mg of cholesterol per serving and per 100 g.
Extra lean	Contains less than 5 g of fat, less than 2 g of saturated fat, and less than 95 mg of cholesterol per serving and per 100 g.

Source: U.S. Food and Drug Administration.

have consumed none.[74] The American Heart Association recommends limiting *trans* fat to 1% of energy (or 2 g based on a 2000-kcal diet).[75] So, if throughout the day someone consumes two servings of products containing 0.49 g of *trans* fat per serving, they will have consumed almost half the recommended maximum while thinking they have not consumed any.ç

The amounts of monounsaturated and polyunsaturated fat are voluntarily included on the labels of some products. For example, in addition to listing the 2 g of saturated fat, the label on a bottle of olive oil may indicate that it contains 2 g of polyunsaturated fat and 10 g of monounsaturated fat per tablespoon. There are no Daily Values for polyunsaturated and monounsaturated fat.

If you want to know the source of fat in a packaged food, you can check the ingredient list. This will show you, for example, if a food contains corn oil, soybean oil, coconut oil, or partially hydrogenated vegetable oil (see Figure 5.22). Labels may also include nutrient content claims such as "low fat," "fat free," and "reduced saturated fat" that describe their fat content (**Figure 5.23**). Food labeling regulations have developed standard definitions for these terms. Food labels may also include health claims related to their fat content. For example, foods low in saturated fat and cholesterol may state that they help to reduce the risk of coronary heart disease (see online Appendix H).

The Role of Reduced-Fat Foods and Fat Replacers

People often choose low-fat and reduced-fat products in order to reduce the total amount of fat and calories in their diets. Some of these foods, such as low-fat and nonfat milk and yogurt, are made by simply removing the fat. In other products, however, the fat is replaced with ingredients that mimic the taste and texture of the fat. Some reduced-fat foods contain added sugars to improve the taste and texture. Some contain soluble fiber or modified proteins that simulate fat, and others contain fats that have been altered to reduce or prevent absorption (**Figure 5.24**).[76] A problem with nonabsorbable fats is that they reduce the absorption of the fat-soluble substances in the diet, including the fat-soluble vitamins, A, D, E, and K. To avoid depleting these vitamins, products made with the nonabsorbable fat substitute Olestra have been fortified with them. However, these products are not fortified with β-carotene and other fat-soluble substances that

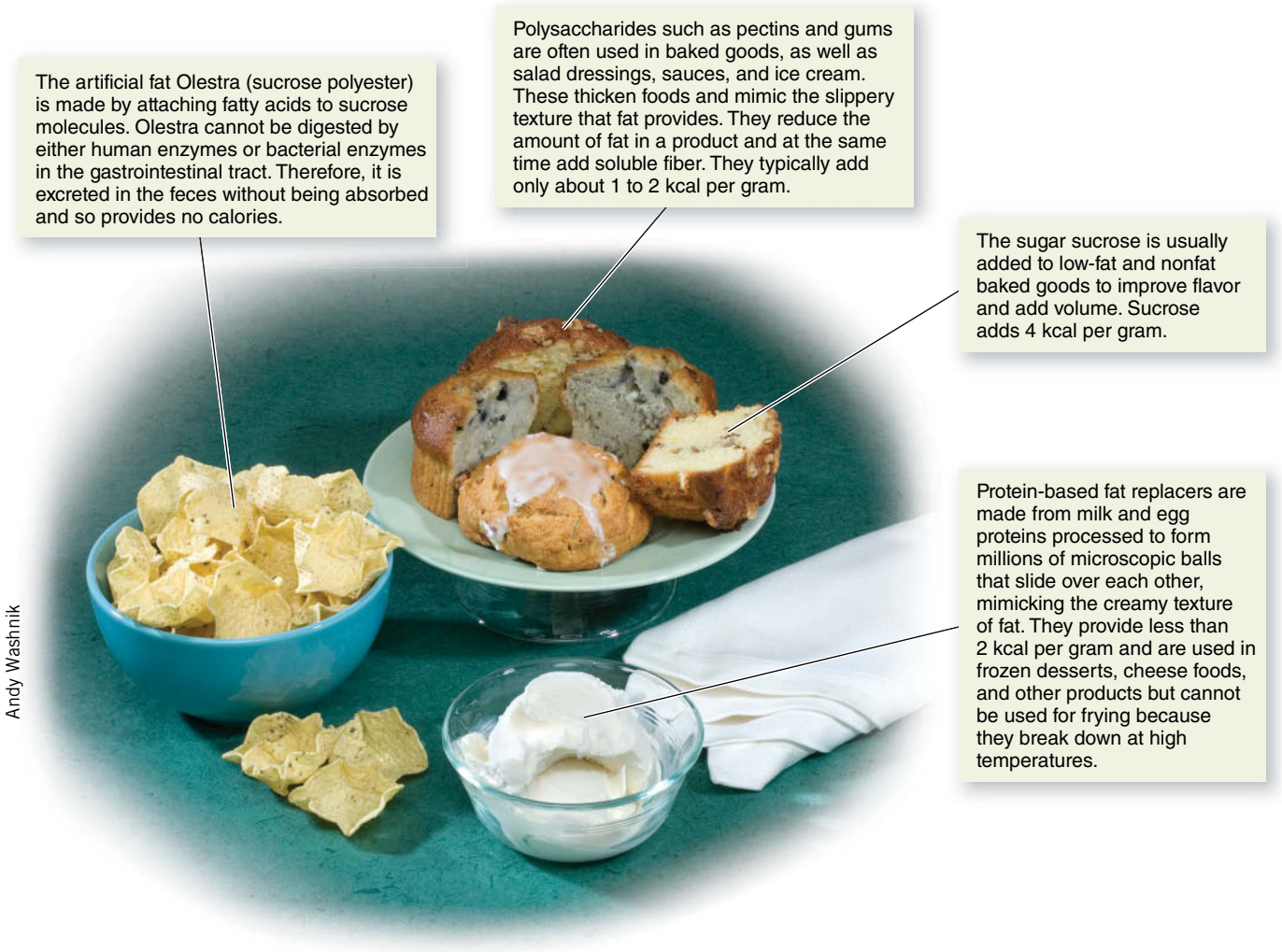


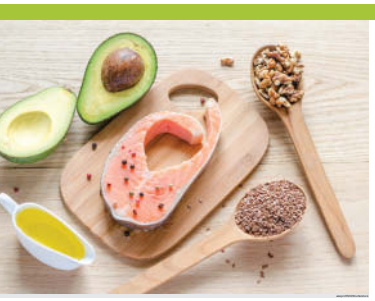
FIGURE 5.24 Fat replacers
Carbohydrates and proteins added to replace fat add calories to foods. In most cases, however, the low-fat food is lower in calories than the original product. Some fat replacers are made from fats that have been modified to reduce how well they can be digested and absorbed. The calories they provide depend on how much is absorbed.

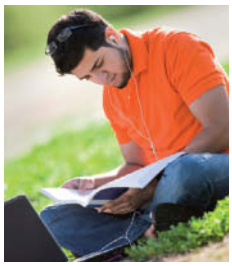
may have health benefits. Another potential problem with Olestra is that it can cause abdominal cramping and loose stools in some individuals because it passes into the colon without being digested.

Will using low-fat and reduced-fat products improve your diet? Some low-fat foods make an important contribution to a healthy diet. Low-fat dairy products are recommended because they provide all the essential nutrients contained in the full-fat versions but have fewer calories and less saturated fat. Using these products increases the nutrient density of the diet as a whole. However, not all reduced-fat foods are nutrient dense. Low-fat baked goods often have more sugar than the full-fat versions because extra sugar is needed to add volume and make up for the flavor that is lost when the fat is removed. Some are just lower-fat versions of nutrient-poor choices, such as cookies and chips. If these reduced-fat desserts and snack foods replace whole grains, fruits, and vegetables, the resulting diet could be low in fat but also low in fiber, vitamins, minerals, and phytochemicals.

Using low-fat foods does not necessarily transform a poor diet into a healthy one or improve overall diet quality, but if used appropriately, fat-modified foods can be part of a healthy diet. For example, if a low-fat salad dressing replaces a full-fat version, it allows you to enhance the appeal of a nutrient-rich salad without as much added fat and calories from the dressing. Low-fat products can also be used in conjunction with weight-loss diets because they are often lower in calories. But check the label. Although most are lower in calories, they are by no means calorie free and cannot be consumed liberally without adding calories to the diet and possibly contributing to weight gain.

OUTCOME





Kyle's friends and relatives had offered lots of advice on how to reduce his risk of heart disease. He tried a few of their suggestions. He was able to stick to a vegetarian diet for only about four days before he decided that wasn't the approach for him and he got tired of fish after eating tuna sandwiches three days in a row. He even tried going to the gym every day for a week but got behind in his schoolwork. Finally, he decided to make more moderate changes. He switched to low-fat dairy products, reduced the portions of red meat he eats, has two or three vegetarian dinners each week, eats at least one tuna sandwich a week, and chooses fish when he eats out to increase his intake of heart-healthy omega-3 fatty acids. Before going to the grocery store, he writes a list to make it easy for him to stock his kitchen with more whole grains and enough fruits and vegetables for six servings each day. Carefully reading food labels helps him avoid *trans* fat, and he uses canola and olive oil when he cooks. The biggest change Kyle made was to increase his activity. In addition to his Frisbee game and workout, he walks everywhere and swims twice a week. **Kyle can't do anything about his family history but he has changed his lifestyle to reduce the risks he can control.**

SUMMARY

5.1 Fats in Our Food

- Lipids add calories, texture, and flavor to our foods.
- The typical American diet contains about 34% of calories from fat. Some of the fats we eat are visible, but others are less obvious. The sources of fat in the American diet have changed during the past 45 years. Americans have reduced their intake of eggs, red meat, whole milk, and butter but have increased the amount of fat they consume from pizza, pasta dishes, snack foods, and fast food, so the amount and type of fat in the diet have changed little.
- Too much of the wrong types of fat increases the risk of chronic disease. A healthy diet includes the right kinds of fats along with plenty of whole grains, fruits, and vegetables.

5.2 Types of Lipids

- Lipids are a diverse group of organic compounds, most of which do not dissolve in water. Triglycerides, commonly referred to as fat, are the most abundant lipid in our diet and our bodies. They consist of a backbone of glycerol with three fatty acids attached. The physical properties and health effects of triglycerides depend on the fatty acids they contain.
- Fatty acids consist of a carbon chain with an acid group at one end. Fatty acids that are saturated with hydrogen atoms are saturated fatty acids and those that contain carbon–carbon double bonds are unsaturated. The length of the carbon chain and the number and position of the carbon–carbon double bonds as well as the configuration of the double bonds determine the physical properties and health effects of fatty acids.
- Phosphoglycerides are a type of phospholipid that consist of a backbone of glycerol, two fatty acids, and a phosphate group. Phosphoglycerides allow water and oil to mix. They are used as emulsifiers in the food industry and in the body they are an important component of cell membranes and lipoproteins.
- Sterols, of which cholesterol is the best known, are made up of multiple chemical rings. Cholesterol is made by the body and consumed in animal foods in the diet. In the body, it is a component of cell membranes and is used to synthesize vitamin D, bile acids, and a number of hormones.

5.3 Lipids in the Digestive Tract

- Some triglyceride digestion begins in the stomach due to the action of gastric lipase. In the small intestine, muscular churning mixes chyme with bile from the gallbladder to break fat into small globules. This allows pancreatic lipase to access these fats for digestion.
- The products of fat digestion (primarily fatty acids and monoglycerides), cholesterol, phospholipids, and other fat-soluble substances combine with bile to form micelles, which facilitate the absorption of these materials into the cells of the small intestine.

5.4 Lipid Transport in the Body

- In body fluids, water-insoluble lipids are transported as lipoproteins. Lipids absorbed from the intestine are incorporated into chylomicrons, which enter the lymphatic system before entering the blood. The triglycerides in chylomicrons are broken down by lipoprotein lipase on the surface of cells lining the blood vessels. The fatty acids released are taken up by surrounding cells and the chylomicron remnants that remain are taken up by the liver.
- Very-low-density lipoproteins (VLDLs) transport lipids from the liver, and with the help of lipoprotein lipase, they deliver triglycerides to body cells. Once the triglycerides have been

removed, intermediate-density lipoproteins (IDLs) remain. These are transformed in the blood into low-density lipoproteins (LDLs). LDLs deliver cholesterol to tissues by binding to LDL receptors on the cell surface.

- High-density lipoproteins (HDLs) are made by the liver and small intestine. They help remove cholesterol from cells and transport it to the liver for disposal.

5.5 Lipid Functions in the Body

- Dietary fat is needed for the absorption of fat-soluble vitamins and to provide essential fatty acids. In the body, triglycerides in adipose tissue provide a concentrated source of energy and insulate the body against shock and temperature changes. Oils lubricate body surfaces.
- Linoleic acid (omega-6) and α-linolenic acid (omega-3) are considered essential fatty acids because they cannot be synthesized by the body. Essential fatty acids are needed for normal structure and function of cell membranes, particularly those in the retina and central nervous system. Hormones synthesized from cholesterol and eicosanoids synthesized from omega-6 and omega-3 polyunsaturated fatty acids have important regulatory roles. Eicosanoids help regulate blood clotting, blood pressure, immune function, and other body processes. The ratio of dietary omega-6 to omega-3 fatty acids affects the balance of omega-6 and omega-3 eicosanoids made and hence their overall physiological effects.
- Triglycerides provide a concentrated source of energy. Throughout the day triglycerides are continuously stored in adipose tissue and then broken down to release fatty acids, depending on the immediate energy needs of the body. After we eat, chylomicrons and VLDLs transport triglycerides to cells. Lipoprotein lipase breaks down the triglycerides so the fatty acids can be taken up by cells and used for energy or storage. When we fast, triglycerides stored in adipocytes are broken down by hormone-sensitive lipase, and the fatty acids and glycerol are released into the blood. To generate ATP from fatty acids, β-oxidation first breaks fatty acids into two carbon units that form acetyl-CoA. In the presence of oxygen, acetyl-CoA can be broken down by the citric acid cycle and ATP produced by the electron transport chain.

5.6 Lipids and Health

Go to WileyPLUS to view a video clip on the Mediterranean diet.

- Atherosclerosis is a disease characterized by deposits of lipids and fibrous material in the artery wall. It is begun by an injury to the artery wall that triggers an inflammatory response that leads to plaque formation. A key event in plaque formation is the oxidation of LDL cholesterol in the artery wall. Oxidized LDL cholesterol is taken up by macrophages, forming foam cells. These burst and deposit cholesterol in the artery wall. Oxidized LDL cholesterol also contributes to plaque formation by promoting inflammation and sending signals that lead to fibrous deposits and blood clot formation.
- High blood levels of LDL cholesterol and triglycerides and low HDL levels increase the risk of heart disease. The risk of heart disease is also increased by diabetes, high blood pressure, obesity, tobacco use, inactivity, a family history of the disease, and a poor diet.
- Individual nutrients and dietary components, whole foods, and dietary patterns affect the risk of heart disease. Diets high in saturated fat and *trans* fatty acids increase the risk of heart disease. Diets high in omega-6 and omega-3 polyunsaturated fatty acids, monounsaturated fatty acids, certain B vitamins, and plant foods containing fiber, antioxidants, and phytochemicals reduce the risk of heart disease. The total dietary and lifestyle pattern is more important than any individual dietary factor in reducing heart disease risk.
- Diets high in fat, particularly animal fat, are associated with an increased incidence of certain types of cancer. Certain types of fatty acids are associated with the growth and development of cancer cells, possibly through their role in eicosanoid synthesis and membrane metabolism.
- Fat contains 9 kcal/g. A high-fat diet therefore increases the likelihood of weight gain, but it is not the primary cause of obesity. Consuming more energy than expended leads to weight gain regardless of whether the energy is from fat, carbohydrate, or protein.

5.7 Meeting Recommendations for Fat Intake

- The DRI recommendations regarding fat include AIs and AMDRs for essential fatty acids and an AMDR for total fat intake of 20 to 35% of energy for adults. To reduce the risk of heart disease, it is recommended that saturated fatty acid intake be limited to less than 10% of total calories by replacing foods high in saturated fat with those high in mono- or polyunsaturated fat. Omega-3 fatty acid intake should be increased to achieve a healthier ratio of omega-6 to omega-3 fatty acids.
- To keep the amount and type of fat in the diet healthy, added fats, protein sources, and processed foods must be chosen carefully. Following the MyPlate recommendations to choose liquid oils rather than solid fats will help provide a healthy amount and ratio of essential fatty acids. Limiting animal fats from the protein and dairy groups reduces saturated fat intake. Choosing fish increases omega-3 fatty acid intake. Eating nuts and seeds increases intakes of both monounsaturated fats and omega-3 fatty acids. Processed foods can be high in saturated and *trans* fats. A diet based on whole grains, fruits, vegetables, nuts, legumes, lean meats, and low-fat dairy products will meet the recommendations for fat intake.
- Low-fat foods are made by removing the fat or by including fat replacers, which simulate the taste and texture of fat. Some fat replacers are made by using mixtures of carbohydrates or proteins to simulate the properties of fat, and some use lipids that are modified to reduce absorption. Low-fat foods and products containing fat replacers can help reduce fat and energy intake when used in moderation as part of a balanced diet.

FOCUS ON Alcohol

© Bill Grove/iStockphoto

CHAPTER OUTLINE

FOCUS 1.1 **What's in Alcoholic Beverages?**

FOCUS 1.2 **Alcohol Absorption and Excretion**

FOCUS 1.3 **Alcohol Metabolism**

- Alcohol Dehydrogenase
- Microsomal Ethanol-Oxidizing System

FOCUS 1.4 **Adverse Effects of Alcohol Consumption**

- What Are the Acute Effects of Alcohol Consumption?
- What Are the Chronic Effects of Alcohol Use?
- What Defines Alcoholism?

FOCUS 1.5 **Benefits of Moderate Alcohol Consumption**

Almost every human culture since the dawn of civilization has produced and consumed some type of alcoholic beverage. These intoxicating beverages are part of religious ceremonies, social traditions, and even medical prescriptions. Sumerian clay tablets dating back to 2100 BCE record physicians' prescriptions for beer. In ancient Egypt, beer and wine were prescribed as part of medical treatment.

Depending on the times and the culture, alcohol use has been touted, casually accepted, denounced, and even outlawed. Today, some people refrain from its use for religious, cultural, personal, and medical reasons, while others enjoy the relaxing effects afforded by drinking these beverages. Whether alcohol consumption represents a risk or provides some benefits depends on who is drinking and how much is consumed. In some groups, moderate alcohol consumption provides health advantages, but excessive alcohol consumption always has medical and social consequences that negatively impact drinkers and their families. When consumed in excess, alcohol can reduce nutrient intake and affect the absorption, storage, mobilization, activation, and metabolism of nutrients. **The breakdown of alcohol produces toxic compounds that damage tissues, particularly the liver.**

F1.1 What's in Alcoholic Beverages?

LEARNING OBJECTIVES

- Explain the difference between alcohol and ethanol.
- Name the sources of the calories provided by alcoholic beverages.

Chemically, any molecule that contains a hydroxyl group (—OH) is an alcohol. Although many molecules are present in our diet and our bodies that can be classified as alcohols, the term *alcohol* refers almost always to **ethanol**, also known as grain alcohol, and often to any beverage that contains ethanol (Figure F1.1). Alcoholic beverages, whether beer, wine, or distilled liquor, consist primarily of water, ethanol, and varying amounts of carbohydrate. The amounts of other nutrients such as protein, vitamins, and minerals are almost negligible. Carbohydrate and alcohol provide the calories in these beverages. An average drink, defined as about 5 fluid ounces (fl oz) of wine, 12 fl oz of beer, or 1.5 fl oz of distilled spirits, contains about 12 to 14 g (about 0.5 oz) of alcohol, which contributes about 90 kcal, or 7 kcal/g. The amount of energy contributed by carbohydrate depends on the type of beverage (Table F1.1).

ethanol The type of alcohol in alcoholic beverages. It is produced by yeast fermentation of sugar.

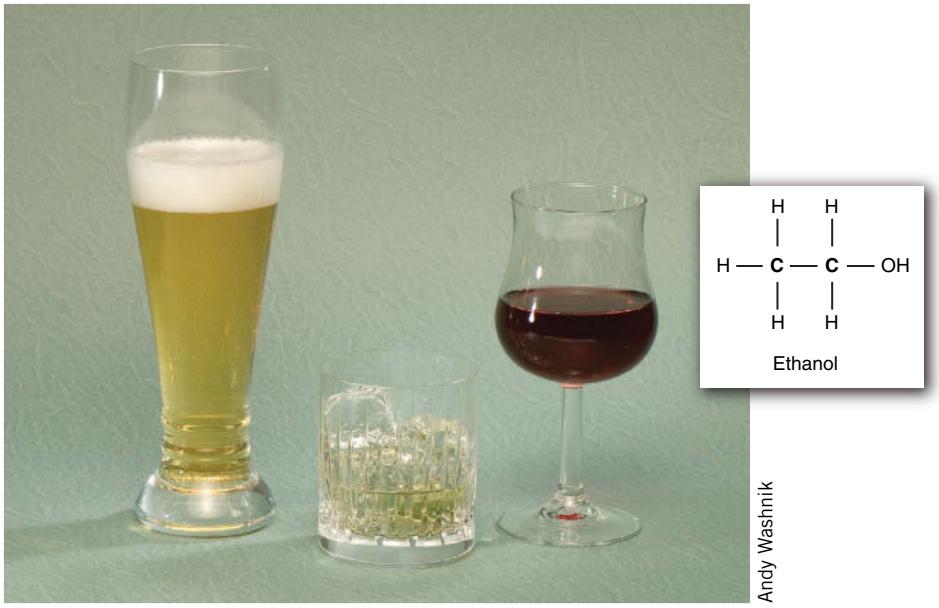


FIGURE F1.1 Sources and structure of ethanol Ethanol, the type of alcohol in all alcoholic beverages, is a small water-soluble molecule. The photo illustrates the amounts of beer, wine, or distilled spirits in an average drink.

TABLE F1.1 Energy, Carbohydrate, and Alcohol Content of Alcoholic Beverages

Beverage	Typical serving (fl oz)	Energy (kcal)	Carbohydrate (g)	Alcohol (g)
Long Island iced tea	7	170	24.3	17.8
Gin and tonic	10	114	10.5	10.7
Wine cooler	12	170	20.2	13.2
Beer	12	146	13.2	12.8
Light beer	12	100	4.6	11.3
White wine	5	100	1.2	13.7
Red wine	5	106	2.5	13.7
Bourbon	1.5	96	0	13.9
Whiskey	1.5	96	0	13.9
Vodka	1.5	96	0	13.9

F1.2 Alcohol Absorption and Excretion

LEARNING OBJECTIVES

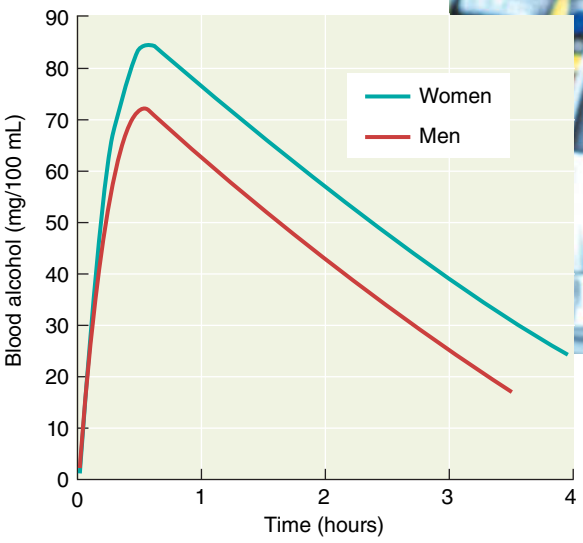
- Explain how food in the stomach affects alcohol absorption.
- Discuss how alcohol is eliminated from the body.

When alcohol is consumed, it is absorbed along the entire gastrointestinal tract by simple diffusion. Only a small amount is absorbed in the mouth and esophagus. Larger amounts are absorbed in the stomach, and the majority of absorption occurs in the duodenum and jejunum of the small intestine. Because alcohol is absorbed rapidly and significant amounts can be absorbed directly from the stomach, the effects of alcohol consumption are almost immediate, especially if it is consumed on an empty stomach. If there is food in the stomach, absorption is slowed because the stomach contents dilute the alcohol, reducing the amount in direct contact with the stomach wall. Food in the stomach also slows absorption because it slows stomach emptying and therefore decreases the rate at which alcohol enters the small intestine, where absorption is the most rapid.

Once absorbed, alcohol enters the bloodstream. It is a small water-soluble molecule and therefore is rapidly distributed throughout all body water compartments. It crosses cell membranes by simple diffusion, so the amount that enters a cell depends on the concentration gradient across the cell membrane. Blood alcohol level therefore reflects the total amount of alcohol in the body and is dependent on the difference between the rates of alcohol absorption and elimination. Peak blood concentrations are attained approximately one hour after ingestion (Figure F1.2A). Many variables, including the kind and quantity of alcoholic beverage consumed, the speed at which the beverage is drunk, the food consumed with it, the weight and gender of

FIGURE F1.2 Blood alcohol concentration

A. Alcohol is absorbed quickly and enters the bloodstream, where levels can be measured. This graph shows blood alcohol levels in men and women after consumption of 0.5 g of alcohol per kilogram of body weight. Equivalent amounts of alcohol cause higher blood alcohol concentrations in women.



Science Photo Library/Photo Researchers, Inc.

B. The amount of alcohol lost in exhaled breath is proportional to the amount of alcohol in the blood. Therefore, a measurement of breath alcohol can be used to estimate blood alcohol level and determine if an individual is driving under the influence of alcohol.

TABLE F1.2 Factors Affecting Blood Alcohol Level

Factor	Effect
Weight	The more people weigh, the more body water they have, so the more dilute the alcohol in their blood is after consuming a given amount.
Gender	Men have more body water and more stomach alcohol dehydrogenase (ADH) activity and thus have a lower blood alcohol level after consuming a standard amount of alcohol than women of the same size.
Food	Food in the stomach slows alcohol absorption, so when food is consumed before drinking, blood alcohol level rises more slowly.
Drinking rate	The body metabolizes alcohol slowly. As the number of drinks per hour increases, blood alcohol level steadily rises.
Type of drink	The amount of alcohol and other ingredients in the drink affects how fast the blood alcohol level rises. When carbonated mixers (such as tonic water or club soda) are used, the body absorbs alcohol more quickly.

the consumer, and the activity of alcohol-metabolizing enzymes in the body, determine blood alcohol level (Table F1.2).

Alcohol can be eliminated by the liver, kidney, and lungs. About 90% of the alcohol consumed is metabolized by the liver. Because alcohol is a toxin and cannot be stored in the body, it must be metabolized rapidly. When alcohol reaches the liver, it is given metabolic priority and is therefore broken down before carbohydrate, protein, or fat. About 5% of consumed alcohol is excreted into the urine. The alcohol that reaches the kidney acts as a diuretic, increasing water excretion. Therefore, excessive alcohol intake can cause dehydration. Alcohol is also eliminated via the lungs during exhalation. The amount lost through the lungs is predictable and reliable enough to be used to estimate blood alcohol level from a measure of breath alcohol (Figure F1.2B).

F1.3 Alcohol Metabolism

LEARNING OBJECTIVES

- Compare the two metabolic pathways that metabolize alcohol.
- Explain why alcohol intake increases fatty acid synthesis.

The two primary metabolic pathways for alcohol metabolism are the **alcohol dehydrogenase (ADH)** pathway, located in the cytosol of the cell, and the **microsomal ethanol-oxidizing system (MEOS)**, located in small vesicles called *microsomes* that form from a membranous organelle called the *smooth endoplasmic reticulum*.

alcohol dehydrogenase (ADH) An enzyme found primarily in the liver and stomach that helps break down alcohol into acetaldehyde, which is then converted to acetyl-CoA.

microsomal ethanol-oxidizing system (MEOS) A liver enzyme system located in microsomes that converts alcohol to acetaldehyde. Activity increases with increases in alcohol consumption.

Alcohol Dehydrogenase

In people who consume moderate amounts of alcohol and/or consume alcohol only occasionally, most of the alcohol is broken down via the ADH pathway. Although liver cells have the highest levels of ADH activity, this enzyme has also been found in all parts of the gastrointestinal tract, with the greatest amounts in the stomach.[1] The amount of alcohol broken down in the stomach may be significant when small amounts of alcohol are consumed. One hypothesis on why women become intoxicated after consuming less alcohol than men is that women have lower activities of this stomach enzyme.[2] Another explanation for why women have higher blood alcohol concentrations than men following the consumption of a standard amount of alcohol is the fact that they have a higher proportion of body fat and thus less body water than men. The alcohol they do consume therefore is distributed in a smaller amount of body water (see Figure F1.2A).

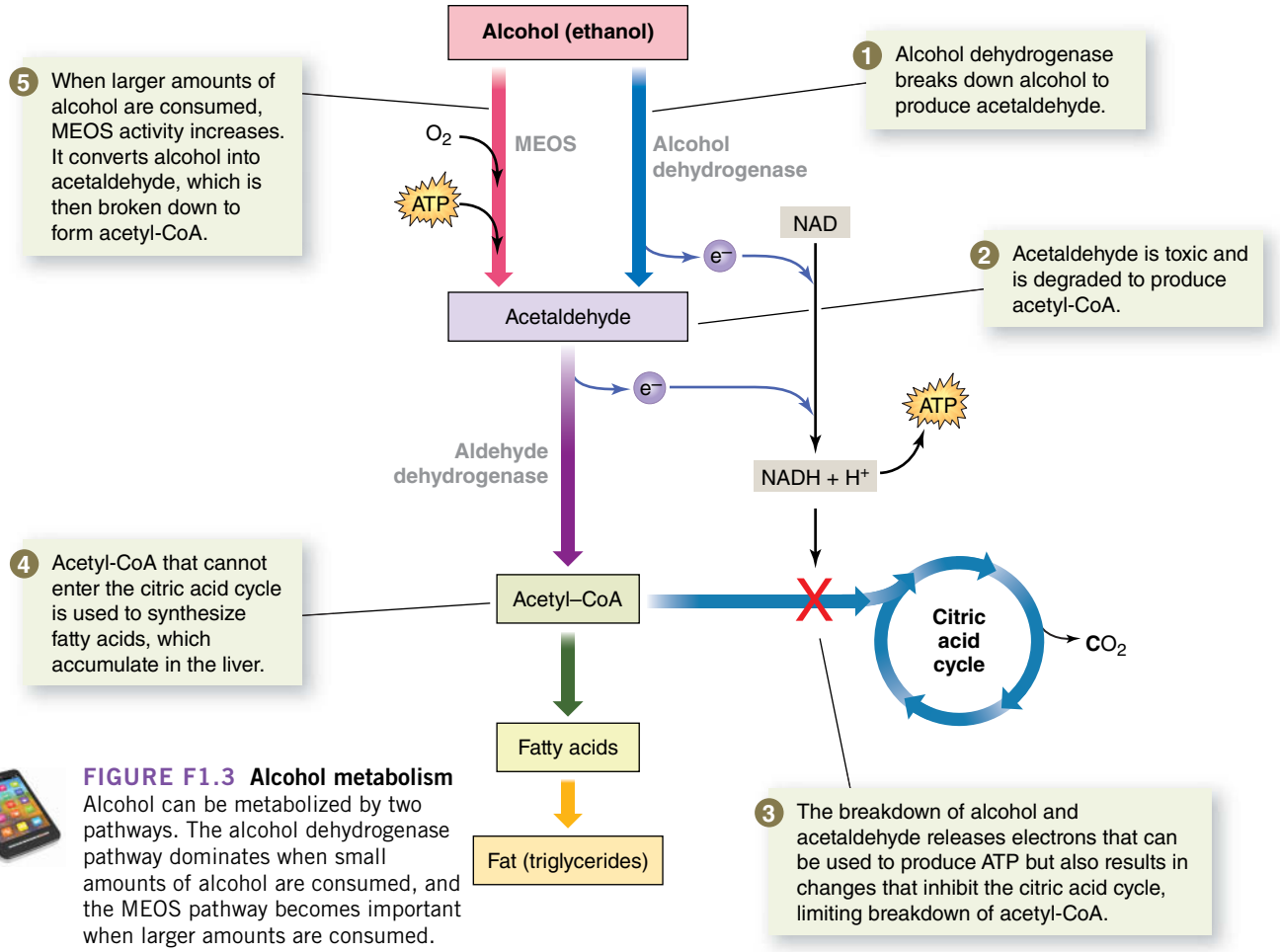


FIGURE F1.3 Alcohol metabolism
Alcohol can be metabolized by two pathways. The alcohol dehydrogenase pathway dominates when small amounts of alcohol are consumed, and the MEOS pathway becomes important when larger amounts are consumed.

ADH converts alcohol to acetaldehyde. Acetaldehyde is a toxic compound that is further degraded by the mitochondrial enzyme aldehyde dehydrogenase to a two-carbon molecule called *acetate* that forms acetyl-CoA (Figure F1.3). These reactions release high-energy electrons and hydrogen ions that are picked up by nicotinamide adenine dinucleotide (NAD), which is a form of the vitamin niacin (see Chapter 8 and the online Focus on Metabolism), to form NADH. Although these processes produce ATP, high levels of NADH slow the citric acid cycle, preventing acetyl-CoA from being further broken down. Instead, the acetyl-CoA generated by alcohol breakdown, as well as acetyl-CoA from carbohydrate or fat metabolism, is used to synthesize fatty acids that accumulate in the liver. Fat accumulation can be seen in the liver after only a single bout of heavy drinking.

Microsomal Ethanol-Oxidizing System

Alcohol can also be metabolized in the liver by the MEOS pathway. This pathway is particularly important when greater amounts of alcohol are consumed. As with alcohol dehydrogenase, MEOS converts alcohol to acetaldehyde, which is then broken down by aldehyde dehydrogenase in the mitochondria (see Figure F1.3). The MEOS pathway requires oxygen and the input of energy to break down alcohol. In addition to forming acetaldehyde and water, reactive oxygen molecules are generated. These reactive molecules can contribute to liver disease. The rate at which ADH breaks down alcohol is fairly constant, but MEOS activity increases when more alcohol is consumed. The MEOS pathway also metabolizes other drugs, so as activity increases in response to high alcohol intake the metabolism of other drugs may be altered.

F1.4 Adverse Effects of Alcohol Consumption

LEARNING OBJECTIVES

- Describe the short-term symptoms of alcohol intoxication.
- Explain why chronic excessive alcohol consumption can lead to malnutrition.
- Describe the long-term effects of excessive alcohol consumption on the liver.
- Discuss the characteristics of alcohol use disorder.

The consumption of alcohol has short-term effects that interfere with organ function for several hours after ingestion. Chronic alcohol consumption also has long-term health effects, and in some individuals, leads to alcohol dependency. Over 40,000 deaths per year are due to acute alcohol toxicity or alcohol-related liver disease.[3] Thousands more result from accidents and homicides associated with alcohol use.

The effects of alcohol vary with life stage. When consumed during pregnancy, alcohol can cause abnormal brain development and other birth defects in the fetus (see Chapter 14). When consumed during childhood and adolescence, when the brain is still developing and changing, alcohol can cause permanent reductions in learning and memory.[4] In everyone, alcohol either directly or indirectly affects every organ in the body and increases the risk of malnutrition and many chronic diseases (Table F1.3).

What Are the Acute Effects of Alcohol Consumption?

Depending on body size, amount of previous drinking, food intake, and general health, the liver can break down about 0.5 oz of alcohol per hour. This is the amount of alcohol in one drink (5 fl oz of wine, 12 fl oz of beer, or 1.5 fl oz of distilled liquor). When alcohol intake exceeds the ability of the liver to break it down, the excess accumulates in the blood and other body fluids until the liver enzymes can metabolize it. The circulating alcohol affects the brain, resulting in impaired mental and physical abilities. In the brain, alcohol acts as a depressant, slowing the rate at which neurological signals are received. First, it affects reasoning; if drinking continues, the

TABLE F1.3 Health Effects of Chronic Alcohol Use

Health Effect	Role of Alcohol
Birth defects	Increases the risk of fetal alcohol spectrum disorders, including fetal alcohol syndrome, when consumed during pregnancy (see Chapter 14).
Gastrointestinal problems	Damages the lining of the stomach and small intestine, and contributes to the development of pancreatitis.
Liver disease	Causes fatty liver, alcoholic hepatitis, and cirrhosis.
Malnutrition	Decreases nutrient absorption and alters the storage, metabolism, and excretion of some vitamins and minerals. Associated with a poor diet because alcohol replaces more nutrient-dense energy sources in the diet.
Neurological disorders	Contributes to impaired memory, dementia, and peripheral neuropathy.
Cardiovascular disorders	Associated with cardiovascular diseases such as cardiomyopathy, hypertension, arrhythmias, and stroke.
Blood disorders	Increases the risk of anemia and infection.
Immune function	Depresses the immune system and results in a predisposition to infectious diseases, including respiratory infections, pneumonia, and tuberculosis.
Cancer	Increases the risk for cancer, particularly of the upper digestive tract—including the esophagus, mouth, pharynx, and larynx—and of the liver, pancreas, breast, and colon.
Sexual dysfunction	Can lead to inadequate functioning of the testes and ovaries, resulting in hormonal deficiencies, sexual dysfunction, and infertility. It is also related to a higher rate of early menopause and a higher frequency of menstrual irregularities (duration, flow, or both).
Psychological disturbances	Causes depression, anxiety, and insomnia, and is associated with a higher incidence of suicide.

TABLE F1.4 Effects of Alcohol on the Central Nervous System

Number of drinks[a]	Blood alcohol[b] (%)	Effect on central nervous system
2	0.05	Impaired judgment, altered mood, relaxed inhibitions and tensions, increased heart rate
4	0.10	Impaired coordination, delayed reaction time, impaired peripheral vision
6	0.15	Unrestrained behavior, slurred speech, blurred vision, staggered gait
8	0.20	Double vision, inability to walk, lethargy
12	0.30	Stupor, confusion, coma
≥14	0.35–0.60	Unconsciousness, shock, coma, death

[a]Each drink contains 0.5 oz of ethanol and is equivalent to 5 fl oz of wine, 12 fl oz of beer, or 1.5 fl oz of distilled liquor.

[b]Values represent blood alcohol, in g/100 mL, approximately one hour after consumption for a 150-lb individual. Actual blood alcohol values depend on the amount of alcohol in the beverage, the rate of consumption, foods consumed with the alcohol, gender, and body weight.

vision and speech centers of the brain are affected. Next, large-muscle control becomes impaired, causing lack of coordination. Finally, if alcohol consumption continues, it can result in **alcohol poisoning**, a serious condition that can slow breathing, heart rate, and the gag reflex, leading to loss of consciousness, choking, coma, and even death (Table F1.4).

alcohol poisoning When the quantity of alcohol consumed exceeds an individual's tolerance for alcohol and impairs mental and physical abilities.

The effects of alcohol on the central nervous system are what make driving while under the influence of alcohol so dangerous. Alcohol reduces reaction time, eye–hand coordination, accuracy, and balance. Not only does alcohol impair one's ability to operate a motor vehicle, but it also impairs one's judgment in the decision to drive. The abuse of alcohol is involved in 31% of all traffic fatalities.[5]

binge drinking A pattern of drinking that brings a person's blood alcohol concentration to 80 mg/100 mL (0.08%) or above.

Binge Drinking Alcohol poisoning occurs most frequently with **binge drinking**. For men, consumption of five or more drinks, and for women consumption of four or more drinks, in about two hours raises blood alcohol enough to be classified as binge drinking. Most of the alcohol consumed by underage drinkers is in the form of binge drinking.[6] Binge drinking is a problem on college campuses that contributes to assault, sexual abuse, injury, and death.[7]

blackout drinking Amnesia following a period of excess alcohol consumption.

Even if the individual does not lose consciousness, excess drinking may still result in memory loss. Drinking enough alcohol to cause amnesia is called **blackout drinking**. Blackout drinking puts people at risk because they have no memory of events that occurred during the blackout. During blackouts, individuals may engage in risky behaviors such as unprotected sexual intercourse, property vandalism, or driving a car—and have no memory of it afterward.

Alcohol and Caffeine The popular trend of consuming alcohol with energy drinks is a dangerous practice that has become a public health concern. The stimulatory effects of caffeine mask the intoxicating effects of alcohol, but caffeine does not change alcohol metabolism. Therefore, consumers of this combination feel wide awake but are still impaired by alcohol, leading to what has been called a state of "wide-awake drunkenness."[8] By making individuals feel less intoxicated, the practice of combining highly caffeinated energy drinks with alcohol can prolong drinking, leading to the consumption of more alcohol than intended, and can lead to risky behaviors such as drunk driving. Due to the safety concerns of consuming caffeine with alcohol, the FDA prohibits the sale of premixed, caffeinated alcoholic beverages, but this does not prevent people from mixing their own energy drinks with alcoholic beverages. Drinkers who combine alcohol with energy drinks are three times more likely to binge drink and are at greater risk of alcohol-related harm and injury than those who do not mix alcohol with energy drinks.[9]

What Are the Chronic Effects of Alcohol Use?

Chronic alcohol consumption can cause disease both because it interferes with nutritional status and because of the toxic compounds produced during alcohol breakdown. Alcohol has its

most significant physiological effects in the liver, but excess alcohol use also increases the risk of hypertension, heart disease, stroke, and cancer.[10,11]

Why Alcohol Abuse Contributes to Malnutrition One of the complications of long-term excessive alcohol consumption is malnutrition. Alcoholic beverages contribute energy but few nutrients; they may replace more nutrient-dense energy sources in the diet, thereby reducing overall nutrient intake. As the percentage of calories from alcohol increases, the risk of nutrient deficiencies rises. With more moderate alcohol intake, the drinker typically substitutes alcohol for carbohydrate in the diet and total energy intake increases slightly. When intake of alcohol exceeds 30% of calories, protein and fat intake as well as carbohydrate intake decrease and consumption of essential micronutrients such as thiamin and vitamins A and C may fall below recommended amounts.[12] Therefore, a diet that is high in alcohol causes primary malnutrition because nutrient-dense energy sources in the diet are replaced by alcoholic beverages, decreasing overall nutrient intake.

In addition to decreasing nutrient intake, alcohol can contribute to a secondary malnutrition by interfering with nutrient absorption or metabolism. Therefore, malnutrition may occur even when adequate amounts of nutrients are consumed. Alcohol causes inflammation of the stomach, pancreas, and intestine, which impairs the digestion of food and absorption of nutrients into the blood. Alcohol damage to the lining of the small intestine decreases the absorption of amino acids, several B vitamins, and vitamin C. Deficiency of the B vitamin thiamin is a particular concern with chronic alcohol consumption (see Chapter 8). The mucosal damage caused by alcohol also increases the ability of large molecules to cross the mucosa. This allows toxins from the gut lumen to enter the portal blood, increasing the liver's exposure to these toxins and, consequently, the risk of liver injury. Alcohol also contributes to malnutrition by altering the storage, metabolism, and excretion of other vitamins and some minerals.

In addition to contributing to undernutrition, alcohol consumption may be related to obesity. Alcohol may contribute to weight gain in some situations because liquids are less satiating than solid food and drinking may stimulate appetite, promoting consumption of additional energy sources. Weight gain is more likely with higher intakes of alcohol and may be affected by the type of alcoholic beverage.[13] Calories consumed as alcohol are more likely to be deposited as fat in the abdominal region. For example, consumption of greater than 500 mL (about 16 oz) of beer per day is associated with abdominal obesity.[14] Excess abdominal fat increases the risk of high blood pressure, heart disease, and type 2 diabetes.

How Alcohol Affects the Liver Alcohol contributes to liver disease both by causing malnutrition and by producing metabolic by-products that damage the liver. Alcoholic liver disease, in turn, exacerbates malnutrition by decreasing food intake and altering nutrient absorption and metabolism.[15]

Alcohol metabolism by both the ADH and MEOS pathways contribute to liver damage. Metabolism via ADH produces excess amounts of the electron carrier NADH. NADH inhibits the citric acid cycle and affects the metabolism of lipids, carbohydrates, and proteins (see Figure F1.3). High levels of NADH favor fat synthesis and inhibit fatty acid breakdown, leading to fat accumulation in the liver. Metabolism by MEOS generates free radicals, resulting in oxidative stress, which causes oxidation of lipids, membrane damage, and altered enzyme activities.[16] Whether broken down by ADH or MEOS, toxic acetaldehyde is formed. Acetaldehyde exerts its toxic effects by altering lipid homoeostasis, stimulating collagen synthesis, and increasing inflammation.[16]

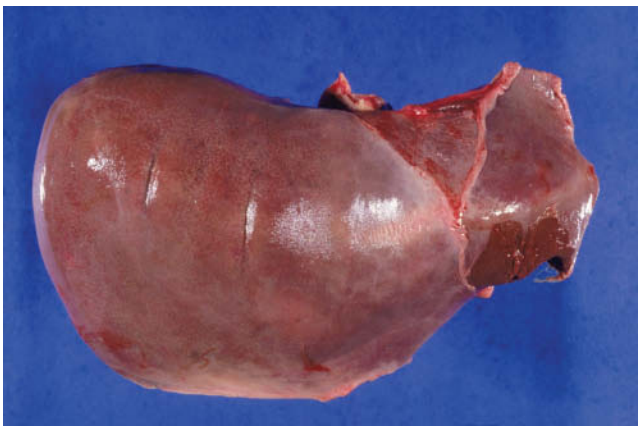
The first phase of alcoholic liver disease is **fatty liver**, a condition that occurs when alcohol consumption increases the synthesis and deposition of fat in the liver. It occurs in almost all people who drink heavily. If drinking continues, this condition may progress to **alcoholic hepatitis**, which is an inflammation of the liver. Both of these conditions are reversible if alcohol consumption is stopped and good nutritional and health practices are followed. If alcohol consumption continues, **cirrhosis** may develop. This is an irreversible condition in which fibrous deposits scar the liver and interfere with its function (Figure F1.4). Because the liver is the primary site of many metabolic reactions, cirrhosis is often fatal.

fatty liver The accumulation of fat in the liver.

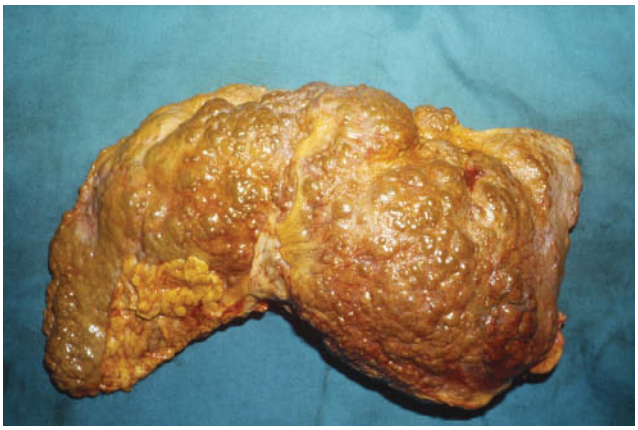
alcoholic hepatitis Inflammation of the liver caused by alcohol consumption.

cirrhosis Chronic liver disease characterized by the loss of functioning liver cells and the accumulation of fibrous connective tissue.

Alcohol and Cancer Alcohol consumption is believed to be related to 3.6% of all cancer cases worldwide.[11] It is associated with an increased risk of cancer of the oral cavity, pharynx,



Martin M. Rotker/Photo Researchers, Inc.



Biophoto Associates/Photo Researchers, Inc.

FIGURE F1.4 Alcoholic cirrhosis
The liver on the left is normal. The one on the right is from a patient with cirrhosis. Cirrhosis is an irreversible condition in which fibrous scar tissue replaces normal liver tissue and interferes with liver function.

esophagus, larynx, breast, liver, colon, rectum, stomach, pancreas, and prostate.[17] Ingestion of all types of alcoholic beverages is associated with an increased cancer risk, supporting the hypothesis that it is alcohol consumption and not some other factor that is responsible.[11] Cancer risk is increased even with modest alcohol intake. For example, epidemiology shows that breast cancer risk is increased with consumption of more than one drink per day.[18] The American Institute for Cancer Research suggests that based on current evidence there is no truly "safe" level of alcohol consumption that does not promote cancer.[19]

Alcohol consumption may increase cancer risk in a variety of ways, and the mechanism may differ depending on the type of cancer. The production of acetaldehyde, a known carcinogen, and the production of reactive oxygen species are two mechanisms that have been proposed.[11] Alcohol is known to cause changes in DNA that may increase the expression of genes that promote cancer.[20] Alcohol may also enhance the effect of other carcinogens, such as those found in tobacco or in the diet. Another factor that may contribute to the carcinogenic effects of alcohol is the nutritional deficiencies associated with chronic alcohol consumption. In addition, alcohol suppresses the immune system, making users more susceptible to infection as well as cancer. In women, alcohol intake increases estrogen levels, possibly contributing to breast cancer.[18]

What Defines Alcoholism?

alcohol use disorder or **alcoholism** A chronic disorder characterized by dependence on alcohol and development of withdrawal symptoms when alcohol intake is reduced.

One risk associated with regular alcohol consumption is the possibility of alcohol dependence. Problem drinking that becomes severe is diagnosed as **alcohol use disorder**, commonly referred to as **alcoholism**. To be diagnosed with an alcohol use disorder, individuals must meet certain criteria outlined in the *Diagnostic and Statistical Manual of Mental Disorders*.[21] Anyone meeting any 2 of the 11 criteria during a 12-month period has alcohol use disorder; the severity—mild, moderate, or severe—is based on the number of criteria met (Table F1.5). Alcohol use disorder, like any other drug addiction, is a physiological problem that needs treatment.

Approximately 17 million adults in the United States ages 18 and older and an estimated 855,000 adolescents ages 12 to17 have been diagnosed with alcohol use disorder.[22] The risk is increased in individuals who begin drinking at a younger age. It is believed to have a genetic component that makes some people more likely to become dependent, but environment also plays a significant role.[23] Thus, someone with a genetic predisposition toward alcohol dependency whose family and peers do not consume alcohol is much less likely to become dependent than someone with the same genes who drinks regularly with friends.

TABLE F1.5 Diagnosing Alcohol Use Disorder[21,22]

In the past year, have you: Answering yes to at least two of these questions indicates an alcohol use disorder **The severity is defined as:** **Mild:** Yes to two to three questions **Moderate:** Yes to four to five questions **Severe:** Yes to six or more questions	Had times when you ended up drinking more or for longer than you intended?
	More than once wanted to cut down or stop drinking, or tried to, but couldn't?
	Spent a lot of time obtaining alcohol, drinking alcohol, or being sick or getting over the aftereffects?
	Experienced craving—a strong need, or urge, to drink?
	Found that drinking—or being sick from drinking—often interfered with taking care of your home or family? Or caused job troubles? Or school problems?
	Continued to drink even though it was causing trouble with your family or friends?
	Given up or cut back on activities that were important or interesting to you, or gave you pleasure, in order to drink?
	More than once gotten into situations while or after drinking that increased your chances of getting hurt (such as driving, swimming, using machinery, walking in a dangerous area, or having unsafe sex)?
	Continued to drink even though it was making you feel depressed or anxious or adding to another health problem? Or after having had a memory blackout?
	Had to drink much more than you once did to get the effect you want? Or found that your usual number of drinks had much less effect than before?
	Found that when the effects of alcohol were wearing off, you had withdrawal symptoms, such as trouble sleeping, shakiness, irritability, anxiety, depression, restlessness, nausea, or sweating? Or sensed things that were not there?

F1.5 Benefits of Moderate Alcohol Consumption

LEARNING OBJECTIVES

- Describe how moderate alcohol intake reduces the risk of cardiovascular disease.
- List three things you could do to reduce the chances of becoming intoxicated while drinking alcoholic beverages.

For some people, moderate alcohol consumption (defined as no more than one drink per day for women and two drinks per day for men) may be beneficial. Consuming alcoholic beverages before or with meals can stimulate appetite and improve mood. It can be relaxing, producing a euphoria that can enhance social interactions. It can also reduce the risk of heart disease, stroke, type 2 diabetes, and overall mortality (Figure F1.5).[24]

Epidemiological and clinical studies have shown that light to moderate drinking reduces the risk for heart disease and stroke when compared to not consuming alcohol at all. This effect is more favorable for middle-age and older adults than for younger people.[24] Since younger individuals have a lower risk of heart disease and are at greater risk of alcohol-related accidents, violence, and overdoses, for them the risks of even moderate drinking may outweigh the benefits. Data also indicate that light to moderate drinking is associated with a reduction in the risk of type 2 diabetes, regardless of the type of alcoholic beverage consumed.[24]

Although the benefits of low to moderate alcohol consumption are believed to be due to the alcohol itself, red wine is generally associated with the most benefit. Wine consumption has been suggested as a reason for the lower incidence of heart disease in the Mediterranean region; the Mediterranean diet includes daily consumption of wine in moderation. And one explanation for the French

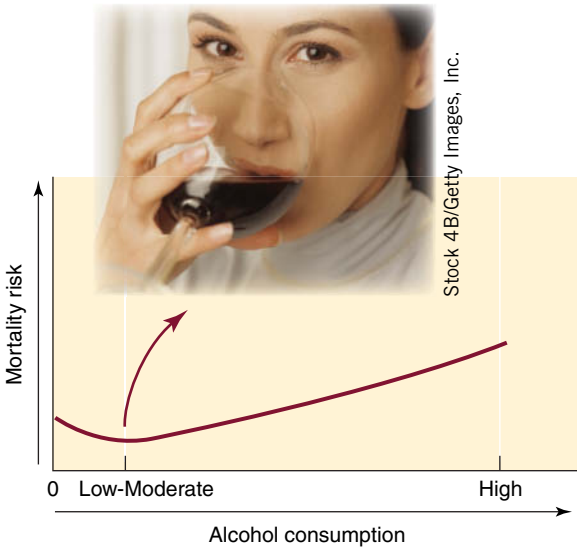


FIGURE F1.5 Alcohol consumption and mortality
The risk of mortality plotted against the amount of alcohol consumed generally results in a J-shaped curve, with lowest mortality at the level that corresponds to low to moderate alcohol consumption. As alcohol consumption increases above this level, so does overall mortality.[27]

paradox—the fact that the French eat a diet that is as high or higher in saturated fat than the American diet but suffer from far less heart disease—is the glass of wine they drink with meals. The particular benefit of red wine is likely due not only to the alcohol but also to the phytochemicals (phenols) it contains.[25,26]

Low to moderate alcohol consumption reduces the risk of heart disease and diabetes in a number of ways (Figure F1.6).[24,28] The most significant is its effect on HDL cholesterol. Moderate alcohol consumption can increase HDL cholesterol by 30% and is believed to account for about half of alcohol's protective effect. Alcohol also lowers the risk of heart disease by reducing platelet stickiness and levels of the blood-clotting protein fibrinogen. Both of these effects reduce the formation of blood clots that can block blood flow to the heart and cause a heart attack. Alcohol intake also increases insulin sensitivity and reduces inflammation.[28,29] Although all of these effects have been documented, the benefit any one individual will gain from moderate alcohol consumption depends on his or her genetic background, health status, and overall lifestyle.

LIFE CYCLE

Not everyone will benefit from low to moderate alcohol consumption. Women who are pregnant or trying to conceive should not consume any alcohol because it can damage the fetus (see Chapter 14). Children and adolescents should not consume alcohol because they are more likely to suffer its toxic effects—drunkenness and poisoning leading to seizures, coma, and death.[7] Individuals who plan to drive or operate machinery should not consume alcohol because it can impair coordination and reflexes. People with alcohol use disorder should avoid alcohol because they cannot restrict their drinking to moderate levels. Finally, individuals taking medications that can interact with alcohol should avoid alcohol. For everyone, the risks of excessive alcohol consumption outweigh the benefits.

Konstantin Sutyagin/Shutterstock

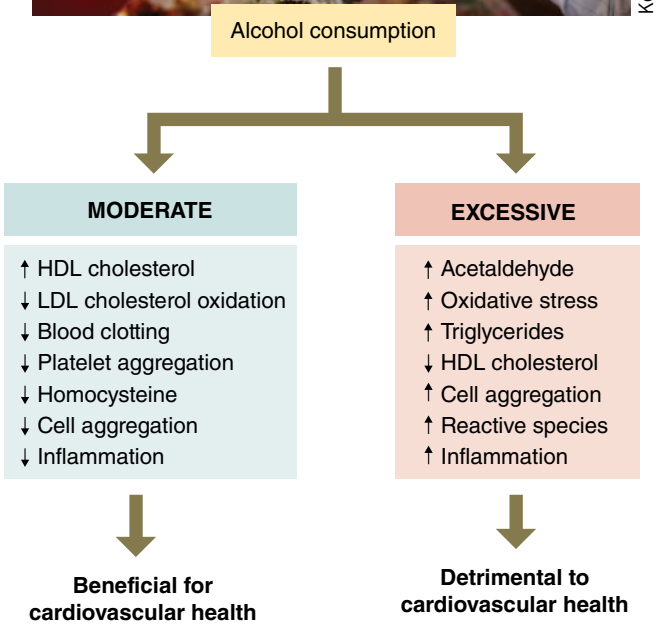


FIGURE F1.6
Cardiovascular benefits and risks of alcohol consumption
Moderate alcohol consumption has effects that reduce the risk of heart disease, but excessive intake contributes to cardiovascular disease risk.

Thomas Tolstrup/Getty Images, Inc.

FIGURE F1.7 Moderate alcohol consumption
When a moderate amount of alcohol is consumed with food, the risk of intoxication is reduced and the potential benefits are enhanced.

Whether or not the benefits of alcohol consumption outweigh the risks, drinking is a personal decision that must take into account medical and social issues. It is not recommended that anyone begin drinking or drink more frequently to obtain alcohol's potential health benefits, because even moderate alcohol consumption is associated with increased risk of breast cancer, violence, drowning, motor vehicle accidents, and injuries from falls.[30,31] Those who do choose to drink should do so in moderation. Alcohol should be consumed slowly, no more than one drink every 1.5 hours. Sipping, not gulping, allows the liver time to break down the alcohol that has already been consumed. Alternating nonalcoholic and alcoholic drinks will also slow down the rate of alcohol intake and prevent dehydration. Alcohol absorption is most rapid on an empty stomach. Consuming alcohol with meals slows its absorption and may also enhance its protective effects on the cardiovascular system (Figure F1.7).[24]

CHAPTER OUTLINE

6.1 Protein in Our Food
- Sources of Protein in Our Diet
- How Protein Sources Impact the Overall Diet

6.2 Protein Molecules
- Amino Acid Structure
- Protein Structure

6.3 Protein in the Digestive Tract
- Protein Digestion
- Amino Acid Absorption
- Why Undigested Protein Can Cause Food Allergies

6.4 Amino Acid Functions in the Body
- Proteins Are Continually Broken Down and Resynthesized
- How Amino Acids Are Used to Synthesize Proteins
- Synthesis of Nonprotein Molecules
- How Amino Acids Provide Energy

6.5 Functions of Body Proteins
- How Proteins Provide Structure
- How Proteins Facilitate and Regulate Body Processes

6.6 Protein, Amino Acids, and Health
- Protein Deficiency
- Protein Excess
- Protein and Amino Acid Intolerances

6.7 Meeting Recommendations for Protein Intake
- How Protein Requirements Are Determined
- Protein Recommendations
- Translating Recommendations into Healthy Diets

6.8 Vegetarian Diets
- What Are the Benefits of Vegetarian Diets?
- Why Some Nutrients Are at Risk of Deficiency in Vegetarian Diets
- How to Plan A Healthy Vegetarian Diet

(©iStockphoto)

lucamanieri/iStockphoto

Proteins and Amino Acids

6

CASE STUDY

Elliot thinks that it will be better for his health if he stops eating animal products. He is a college student who eats some of his meals at the dining halls and cooks his other meals. He doesn't know much about nutrition, but he knows that the dining halls offer vegetarian choices at every meal. What he doesn't realize is that, although their vegetarian meals don't contain meat, many contain eggs and dairy products. He had planned to eliminate these from his diet as well as meat.

In starting his new eating plan, Elliot thought breakfast would be easy, but as he poured himself a bowl of cereal, he realized that milk was an animal product so he made a note to pick up some soymilk. He decided on toast instead, and since the butter he had in the refrigerator was an animal product, he had peanut butter on his toast. He likes cream in his coffee, but when he read the label on his nondairy creamer he was astonished to find that it contained milk protein. Tomorrow he will use soymilk in his coffee. For lunch he has a veggie and cheese sub, without the cheese. This meal wasn't very filling, so on the way home he bought a big bag of chips—at least these didn't contain any animal products.

For dinner that night the dining hall had vegetarian lasagna, but it was full of cheese. So he just had some pasta with marinara sauce and a salad. Ice cream for dessert was out so he opted for a slice of apple pie once he was assured it didn't contain any animal products. **By the end of the day, he was frustrated and hungry and wondered whether his vegan diet would provide enough protein and other nutrients to keep him healthy.**

© Chris Schmidt/iStockphoto

6.1 Protein in Our Food

LEARNING OBJECTIVES

- Identify the foods groups that provide the most concentrated sources of protein.
- Compare the nutrients provided by animal and plant sources of protein.

Protein is plentiful in the American food supply; typical protein intake for adults is about 88 g/day, well above the requirement.[1,2] Most people in the United States and other developed countries have access to a variety of protein sources: animal sources including meats, eggs, and dairy products; and plant sources such as legumes, nuts, seeds, and grains. With the variety of foods available, even those who choose a vegetarian diet can easily meet their protein needs. Yet many people still worry about getting enough protein. Protein drinks, pills, and powders fill the shelves of health-food stores. Consumers often choose high-protein foods and supplements because protein is associated with good health. Protein is promoted to keep minds sharp and hair shiny and to aid in weight loss. Unlike carbohydrate and fat, the popular press associates protein only with positive effects. It has not been accused of being fattening, causing tooth decay, or increasing the risk of heart disease.

Sources of Protein in Our Diet

Most people around the world rely on plant proteins from grains, legumes and other vegetables, nuts, and seeds to meet their needs. These foods tend to be more available and less expensive than animal sources of protein. For example, in rural Mexico, most of the protein in the diet comes from beans, rice, and tortillas; in India, protein comes from lentils and rice; in China, rice with small amounts of meat and soy provides the protein. As the economic prosperity of a population grows, the proportion of animal foods in its diet typically increases.

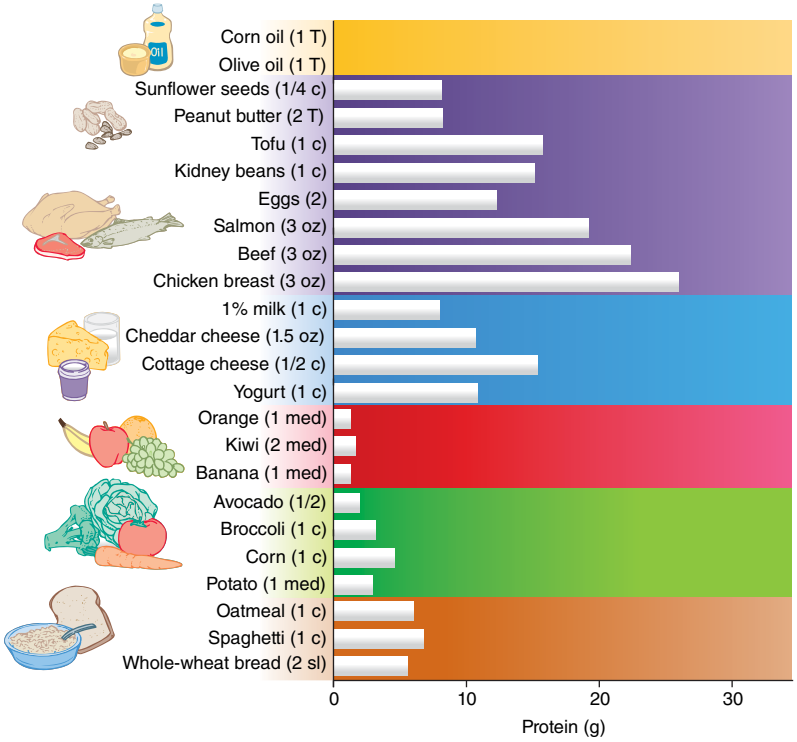
In the United States, about two-thirds of the dietary protein comes from meat, poultry, fish, eggs, and dairy products.[3] These animal products are the most concentrated sources of protein. One egg contains about 7 g of protein, a cup of milk contains 8 g, and a 3-oz serving of meat, fish, or poultry provides over 20 g. But plant foods such as grains and legumes are also important sources of protein. Legumes, such as lentils, soybeans, peanuts, black-eyed peas, chickpeas, and kidney beans, provide about 6 to 10 g of protein per half-cup serving. Nuts and seeds provide about 5 to 10 g per quarter cup. Even bread, rice, and pasta provide protein—about 2 to 3 g per slice or half cup (Figure 6.1). Although most plant sources of protein are not used as efficiently by the human body as animal sources, they can still easily meet most people's needs.

How Protein Sources Impact the Overall Diet

The source of the protein in the diet determines what other nutrients are consumed along with it. Animal products provide an excellent source of B vitamins and minerals such as iron, zinc, and calcium. But animal products provide no fiber and are often high in saturated fat—a combination that increases the risk of heart disease. Plant sources of protein are a good source of most, but not all, B vitamins, and they also supply iron, zinc, and calcium but in less absorbable forms. But foods that provide good sources of plant proteins also contain fiber, phytochemicals, and unsaturated fats—dietary components that should be increased to promote health. Recommendations suggest that our diets be plant-based, meaning that most of our diet should be made up of foods such as whole-grains, legumes and other vegetables, fruits, nuts, and seeds with smaller amounts of seafood, lean meat and poultry, and low-fat dairy products. Following these guidelines will provide plenty of protein but without an over-reliance on animal sources of protein.[1]

FIGURE 6.1 Protein comes from plant and animal foods

A. Animal products such as meat, fish, poultry, eggs, and dairy products provide the most concentrated sources of protein; plant sources, such as legumes, nuts, and seeds, are also excellent sources. Grains are lower in protein but make an important protein contribution because we consume multiple servings daily.



Pixtal/SUPERSTOCK

© ACE STOCK LIMITED/Alamy

B. Animal sources of protein are high in iron, zinc, and calcium but also add saturated fat to the diet. Plant sources of protein are rich in fiber, phytochemicals, and unsaturated oils.

6.2 Protein Molecules

LEARNING OBJECTIVES

- Describe the general structure of an amino acid, a polypeptide, and a protein.
- Distinguish between essential and nonessential amino acids.
- Discuss how the order of amino acids in a polypeptide chain affects protein structure and function.

A protein molecule, whether found in a steak, a kidney bean, or a part of the human body, is constructed of one or more folded, chain-like strands of **amino acids**. The amino acid chains of each type of protein molecule contain a characteristic number and proportion of amino acids that are bound together in a precise order. The chains fold into specific configurations, giving each protein a unique three-dimensional shape that is essential to its particular function. Variations in the number, proportion, and order of amino acids in the chains allow for an infinite number of different protein structures.

amino acids The building blocks of proteins. Each contains a central carbon atom bound to a hydrogen atom, an amino group, an acid group, and a side chain.

Like carbohydrates and lipids, protein molecules contain the elements carbon, hydrogen, and oxygen, but proteins are distinguished from carbohydrates and triglycerides by the presence of the element nitrogen in their structure.

Amino Acid Structure

Approximately 20 amino acids are commonly found in proteins. Each amino acid consists of a carbon atom bound to four chemical groups: a hydrogen atom; an amino group, which contains nitrogen; an acid group; and a fourth group or side chain that varies in length and structure

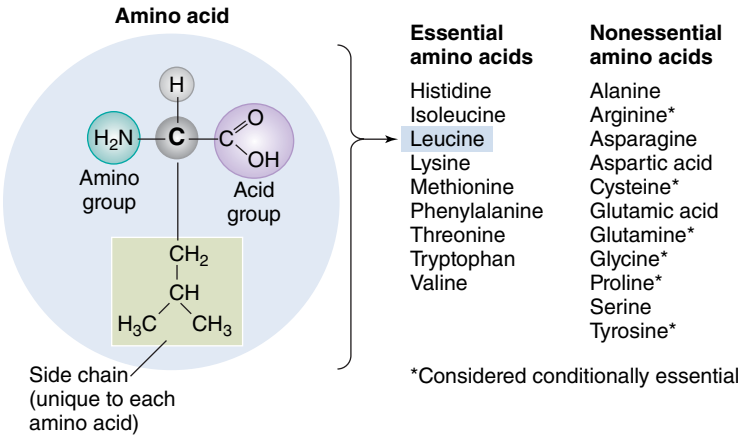


FIGURE 6.2 Amino acid structure
All amino acids have a similar structure, but each has a different side chain. Those that cannot be made in the body, such as leucine shown here, are considered essential.

(Figure 6.2). Different side chains give specific properties to individual amino acids.

Of the 20 amino acids commonly found in protein, 9 cannot be made by the adult human body. These amino acids, called **essential** or **indispensable amino acids**, must be consumed in the diet (see Figure 6.2). If the diet is deficient in one or more of these amino acids, new proteins containing them cannot be made without breaking down other body proteins to provide them. The 11 **nonessential** or **dispensable amino acids** can be made by the human body and are not required in the diet. When the diet does not provide enough of the nonessential amino acids, most can be made by the process of **transamination**, in which an amino group from one amino acid is transferred to a carbon-containing molecule to form a different amino acid (Figure 6.3).

essential or **indispensable amino acid** An amino acid that cannot be synthesized by the human body in sufficient amounts to meet needs and therefore must be included in the diet.

nonessential or **dispensable amino acid** An amino acid that can be synthesized by the human body in sufficient amounts to meet the body's needs.

transamination The process by which an amino group from one amino acid is transferred to a carbon compound to form a new amino acid.

conditionally essential amino acid An amino acid that is essential in the diet only under certain conditions or at certain times of life.

dipeptide Two amino acids linked by a peptide bond. A **tripeptide** is three amino acids linked by peptide bonds, and a **polypeptide** refers to a chain containing many amino acids linked by peptide bonds.

Some amino acids are **conditionally essential**; that is, they are essential only under certain conditions. For example, the conditionally essential amino acid tyrosine can be made in the body from the essential amino acid phenylalanine. If phenylalanine is in short supply, tyrosine cannot be made and becomes essential in the diet. Likewise, the amino acid cysteine is essential only when the essential amino acid methionine is in short supply or cannot be converted to cysteine. Other amino acids may be essential at certain times of life, such as premature infancy, or due to certain conditions, such as metabolic abnormalities or physical stress.

Protein Structure

To form proteins, amino acids are linked together by peptide bonds, which are the linkages that form between the acid group of one amino acid and the nitrogen atom of the next amino acid (Figure 6.4). When two amino acids are linked with a peptide bond, the molecule formed is called a **dipeptide**; when three amino acids are linked, they form a **tripeptide**. Many amino acids bonded together constitute a **polypeptide**.

Why Proteins Have Three-Dimensional Shapes A protein is made of one or more polypeptide chains folded into a complex three-dimensional shape (see Figure 6.4). The order and chemical properties of the amino acids in a polypeptide chain determine the three-dimensional shape of the protein. Folds and bends in the chain occur when some of the amino acids attract each other and others repel each other. For example, amino acids at various places along the

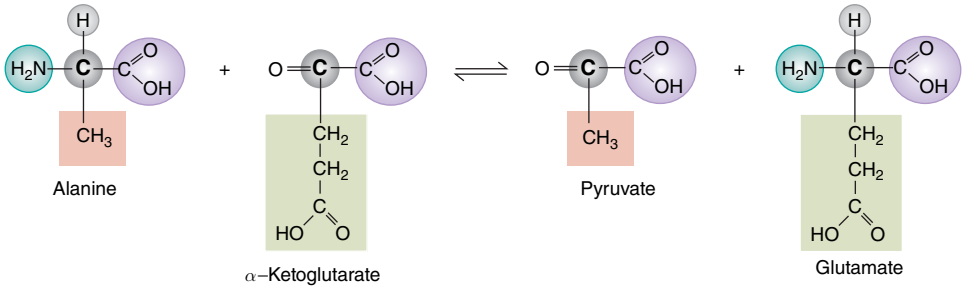


FIGURE 6.3 Transamination
In this example, transamination transfers the amino group from the nonessential amino acid alanine to the carbon compound alpha-ketoglutarate (α-ketoglutarate) to form the three-carbon compound pyruvate and the essential amino acid glutamate.

chain that are attracted to each other may cause segments of the chain to coil like a telephone cord. Amino acids that are attracted to water will orient to the outside of the structure to be in contact with body fluids, whereas amino acids that repel water will fold to the inside to be away from body fluids. After polypeptide chains have folded, several chains may bind together to form the final protein.

How Protein Structure Contributes to Function

It is the shape of the final protein that determines its function. For example, the elongated shape of the connective tissue proteins, collagen and α-keratin, allows them to give strength to fingernails and ligaments. The oxygen-carrying protein hemoglobin has a spherical shape, which allows proper functioning of the red blood cells. If the shape of a protein is altered, its function may be disrupted. For example, in sickle cell disease, an inherited abnormality in DNA causes a change in the amino acid sequence in the hemoglobin molecule. This alters the shape of the molecule and as a result, the hemoglobin molecules bind together in long chains. Thus, under certain circumstances, rather than having the disc shape characteristic of normal red blood cells, red blood cells containing these rope-like strands of sickle cell hemoglobin take on a distorted shape that resembles a crescent or sickle (Figure 6.5). Sickle-shaped red blood cells can block capillaries, causing inflammation and pain. They also rupture easily, leading to anemia from a shortage of red blood cells.

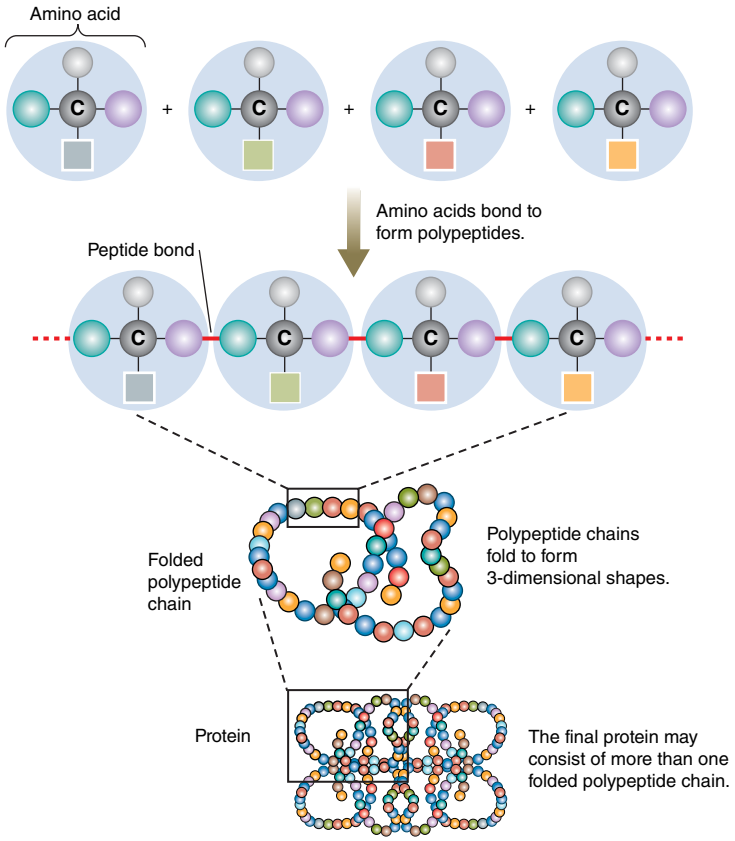


FIGURE 6.4 Proteins are made from amino acids
When many amino acids are joined by peptide bonds, which link the acid group (shown in purple) of one amino acid to the amino group (shown in turquoise) of another, they form a polypeptide. The chemical properties of the amino acids in the polypeptide chain cause it to fold, contributing to the three-dimensional structure of the protein. The final protein may include one or more folded polypeptide chains.

Changes in protein structure can be caused by changes in the physical environment of the protein, such as an increase in temperature or a change in acidity. Such changes cause protein **denaturation**. In food, the heat of cooking denatures protein, thereby changing its shape and physical properties. For example, an egg white becomes hard

denaturation The alteration of a protein's three-dimensional structure.

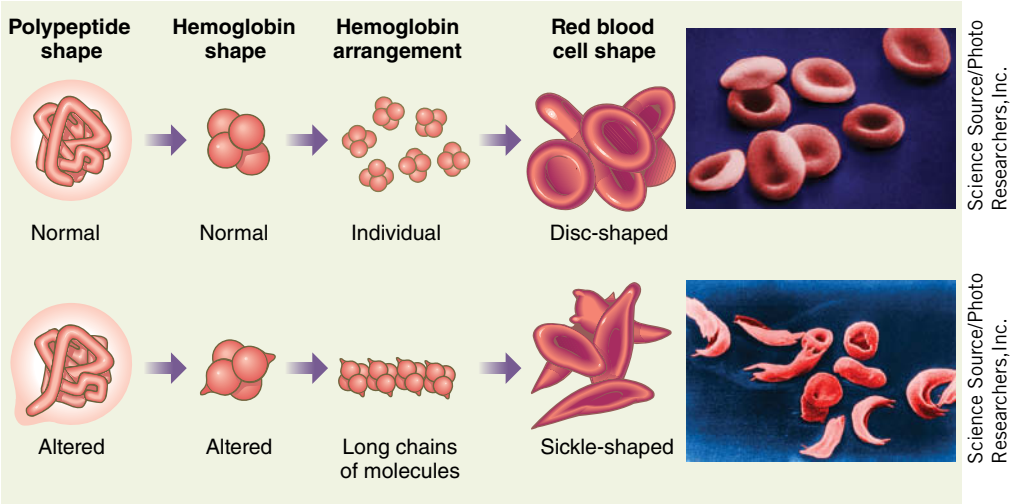


FIGURE 6.5 Sickle cell disease
In sickle cell disease, a change in the sequence of amino acids in hemoglobin alters the shape and function of the protein molecule. Sickle cell hemoglobin forms long chains that distort the shape of red blood cells.

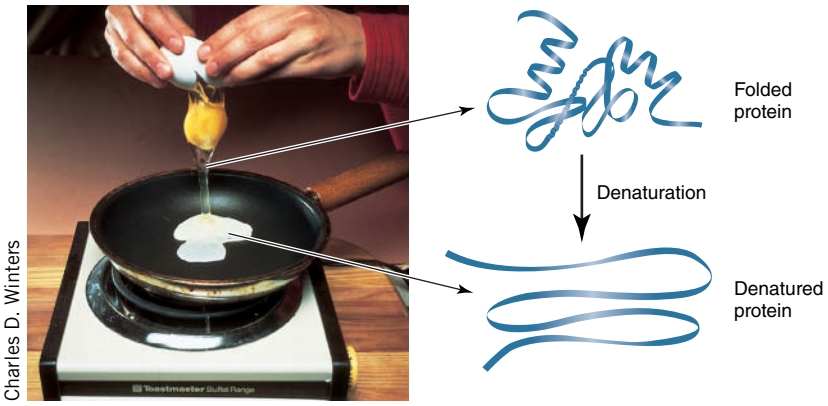


FIGURE 6.6 Denaturation changes a protein's physical properties
When an egg is cooked, the heat denatures the protein, causing the polypeptide chains to unfold. The protein in a raw egg white forms a clear, viscous liquid, but when cooking denatures it, the egg white becomes white and firm and cannot be restored to its original form.

and opaque after the protein it contains is denatured by cooking (Figure 6.6). The denaturation of proteins in our food also creates other characteristics we desire. For example, whipped cream is made when mechanical agitation denatures the protein in cream, and yogurt forms when acid denatures the proteins in milk.

6.3 Protein in the Digestive Tract

LEARNING OBJECTIVES

- Describe protein digestion and amino acid absorption.
- Explain why consuming an excess of one amino acid can cause a deficiency of another amino acid.
- Discuss how protein digestion is related to food allergies.

Protein enters the digestive tract from food, from digestive secretions, and from sloughed gastrointestinal cells. No matter what the source, the protein must be broken down to amino acids before entering the bloodstream.

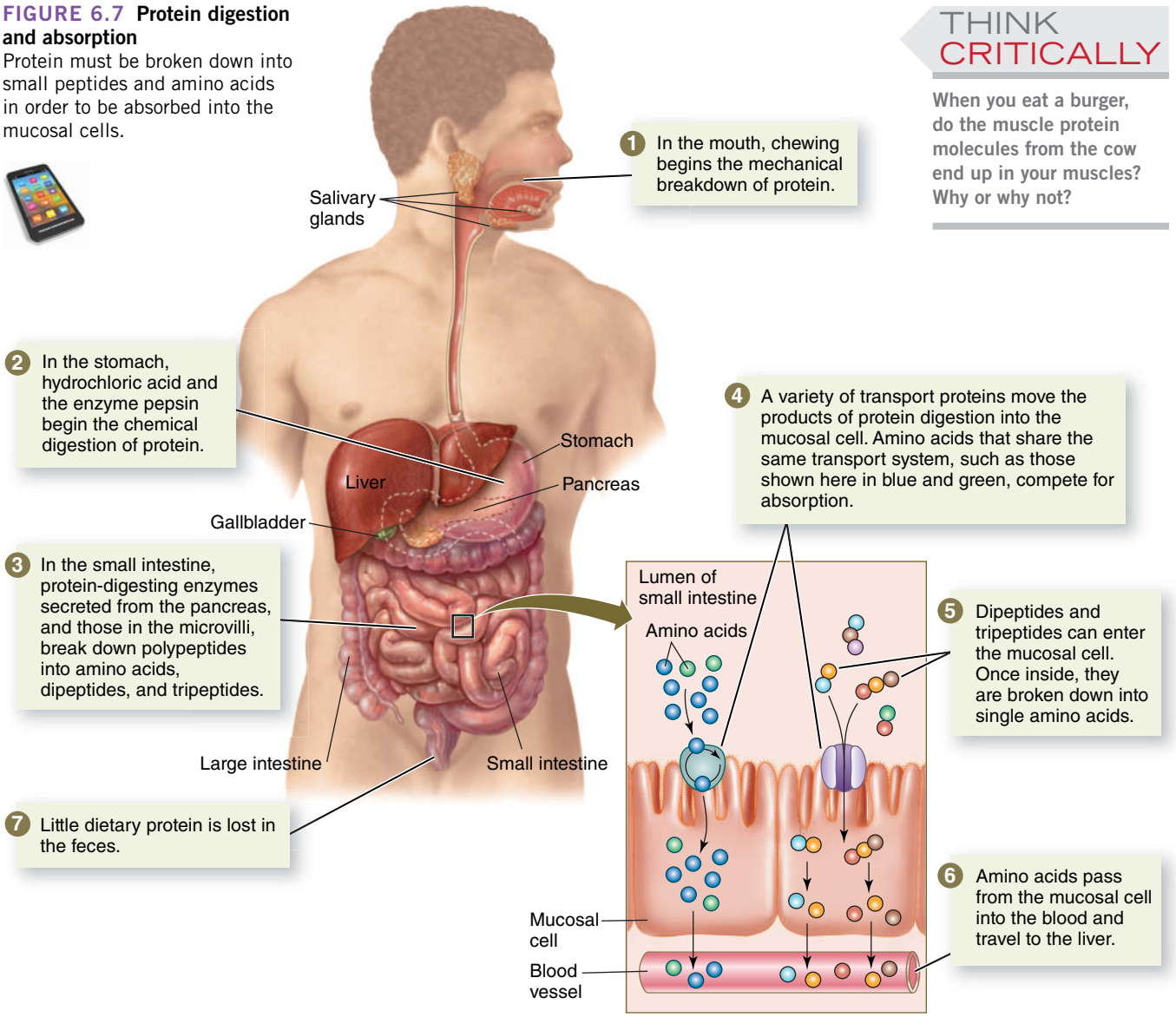
Protein Digestion

The chemical digestion of protein begins in the stomach, where hydrochloric acid denatures proteins, opening up their folded structure to make them more accessible to enzyme attack (Figure 6.7). The acid also activates the protein-digesting enzyme pepsin, which breaks some of the peptide bonds in the polypeptide chains, leaving shorter polypeptides. Most protein digestion occurs in the small intestine where polypeptides are broken into tripeptides, dipeptides, and amino acids by pancreatic protein-digesting enzymes such as trypsin and chymotrypsin and by protein-digesting enzymes in the microvilli of the small intestine. Single amino acids, dipeptides, and tripeptides can be absorbed into the mucosal cells of the small intestine. Once inside, they are broken into single amino acids (see Figure 6.7).

Amino Acid Absorption

Amino acids and di- and tripeptides enter the mucosal cells of the small intestine using one of several active transport systems. Amino acids with similar structures share the same transport system and therefore compete for absorption. For instance, the amino acids leucine, isoleucine, and valine, referred to as branched-chain amino acids because their carbon side chains have a branching structure (see online Appendix K), share the same transport system. If there is an excess of any one of the amino acids sharing a transport system, more of it will be absorbed, slowing the absorption of the other competing amino acids (see Figure 6.7). This is generally not a problem when amino acids are consumed in foods because foods contain a

FIGURE 6.7 Protein digestion and absorption
Protein must be broken down into small peptides and amino acids in order to be absorbed into the mucosal cells.



THINK CRITICALLY

When you eat a burger, do the muscle protein molecules from the cow end up in your muscles? Why or why not?

variety of amino acids without disproportionately large amounts of any one. However, taking a supplement of one amino acid can provide enough of it to impair absorption of other amino acids that share the same transport system. For example, weight lifters often take supplements of the amino acid arginine in hopes of stimulating muscle growth, but because arginine shares the same transport system as lysine, large doses of arginine reduce the absorption of lysine.

Why Undigested Protein Can Cause Food Allergies

Food allergies are triggered in susceptible individuals when an incompletely digested protein from the diet stimulates the immune system (see Chapter 3). When the same protein is consumed again, the immune system sees it as a foreign substance and mounts an attack, causing an allergic reaction. Allergic reactions to food can cause symptoms throughout the body. These reactions can involve the digestive system, causing vomiting or diarrhea; the skin, causing a rash or hives; the respiratory tract, causing difficulty breathing; or the cardiovascular system, causing a drop in blood pressure. A rapid severe allergic reaction that involves more than one part of the body is called **anaphylaxis**. A severe anaphylactic reaction can cause breathing difficulty or a dangerous drop in blood pressure and can be fatal. The proteins from milk, eggs, peanuts, tree nuts, wheat, soy, fish, and shellfish are common causes of food allergies.

anaphylaxis An immediate and severe allergic reaction to a substance (e.g., food or drugs). Symptoms include breathing difficulty, loss of consciousness, and a drop in blood pressure and can be fatal.

Allergies are common in people with gastrointestinal disease because their damaged intestine allows more absorption of incompletely digested proteins. Allergies are also common in infants because their immature gastrointestinal tracts are more likely to allow larger polypeptides to be absorbed. Once an infant's intestinal mucosa matures, absorption of incompletely digested proteins is less likely and some food allergies disappear. The absorption of whole proteins by very young infants, however, can also be of benefit since antibody proteins absorbed from breast milk can provide temporary protection against certain diseases (see Chapter 14).

6.4 Amino Acid Functions in the Body

LEARNING OBJECTIVES

- Describe the sources of the amino acids entering the amino acid pool and the uses for amino acids that leave the pool.
- Explain what is meant by the term *limiting amino acid*.
- Discuss the steps involved in synthesizing proteins.
- Describe the conditions under which the body uses protein to provide energy.

amino acid pool All of the amino acids in body tissues and fluids that are available for use by the body.

Once dietary proteins have been digested and absorbed, their constituent amino acids become available to the body. The amino acids in body tissues and fluids are referred to collectively as the **amino acid pool** (Figure 6.8). Amino acids enter the available pool from the diet and from the breakdown of body proteins. Of the approximately 300 g of protein synthesized by the body each day, only about 100 g are made from amino acids consumed in the diet. The other 200 g are produced by the recycling of amino acids from protein broken down in the body. Amino acids in this pool can be metabolized to provide energy—4 kcal/g. This occurs both when the diet contains protein in excess of needs and when the diet is low in energy. When the diet is low in energy, amino acids are also used to synthesize glucose, and when protein and energy are consumed in excess, amino acids can be used to synthesize fatty acids. When dietary intake of protein and energy is adequate but not excessive, most amino acids in the amino acid pool are used to synthesize body proteins and other nitrogen-containing compounds.

Proteins Are Continually Broken Down and Resynthesized

protein turnover The continuous synthesis and breakdown of body proteins.

Body proteins are not static but rather are continually broken down and resynthesized. This process, referred to as **protein turnover**, is necessary for normal growth and maintenance of body tissues and for adaptation to changing situations. The rate at which proteins are made

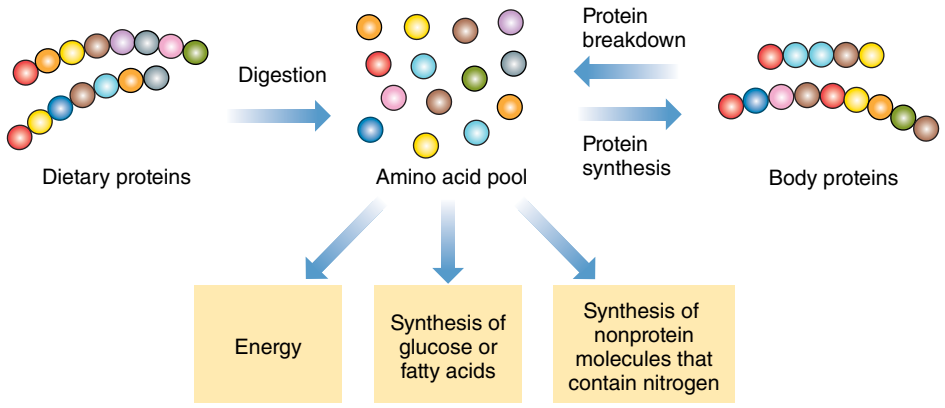


FIGURE 6.8 Amino acid pool
Amino acids in the available pool come from the diet and from the breakdown of body proteins. They are used to synthesize body proteins and nonprotein molecules, and to provide energy as ATP or to synthesize glucose or fatty acids.

and degraded varies with the protein and is related to its function. Proteins whose concentration must be regulated and proteins that act as chemical signals in the body tend to have high rates of turnover—that is, synthesis and degradation. For example, the level of insulin in the blood can be rapidly increased by increasing its synthesis and decreasing its degradation. To decrease insulin levels, breakdown can be increased and synthesis slowed. Varying levels of synthesis and degradation allow the amounts of specific proteins to adjust quickly to maintain homeostasis as body conditions change. Structural proteins, such as collagen in connective tissue, have slower rates of turnover. The total amount of body protein broken down each day is large; twice as many of the amino acids in the amino acid pool come from recycled proteins as from dietary proteins.

How Amino Acids Are Used to Synthesize Proteins

The amino acids used to synthesize body proteins come from the amino acid pool. The instructions that dictate which amino acids are needed, and in what order they should be combined, are contained in stretches of DNA called **genes**. When a protein is needed, the process of protein synthesis begins.

The first step in protein synthesis involves copying, or transcribing, the DNA code from the gene into a molecule of *messenger RNA (mRNA)*. This process is called **transcription** (Figure 6.9). The mRNA then takes this information from the nucleus of the cell to ribosomes in the cytosol, where proteins are made. Here the information in mRNA is translated through another type of RNA, called *transfer RNA (tRNA)*. Transfer RNA reads the code and delivers the needed amino acids to form a polypeptide chain. This process is called **translation**. After translation, polypeptides typically undergo further chemical modifications before achieving their final protein structure and function (see **Science Applied: How Bacteria Created the Field of Biotechnology**).

gene A length of DNA containing the information needed to synthesize RNA, which may translate into a polypeptide sequence.

transcription The process of copying the information in DNA to a molecule of mRNA.

translation The process of translating the mRNA code into the amino acid sequence of a polypeptide chain.

gene expression The process by which the information coded in a gene is used to synthesize a product, either a protein or a molecule of RNA.

Why Genes Are Regulated

Gene expression is the process whereby the information coded in a gene is used to produce a protein or other gene product. When a gene is expressed, the product for which the gene codes is synthesized. Sometimes the final product is a molecule of RNA, and sometimes it is a protein. Which gene products are made and when they are made are important to the health of the cell and the organism, and therefore gene expression is carefully regulated. Not all genes are expressed in all cells or at all times. For example, the hormone glucagon is a protein that is made by cells in the pancreas. Glucagon is not made by other body cells because the gene is not expressed in cells other than those in the pancreas. The expression of some genes

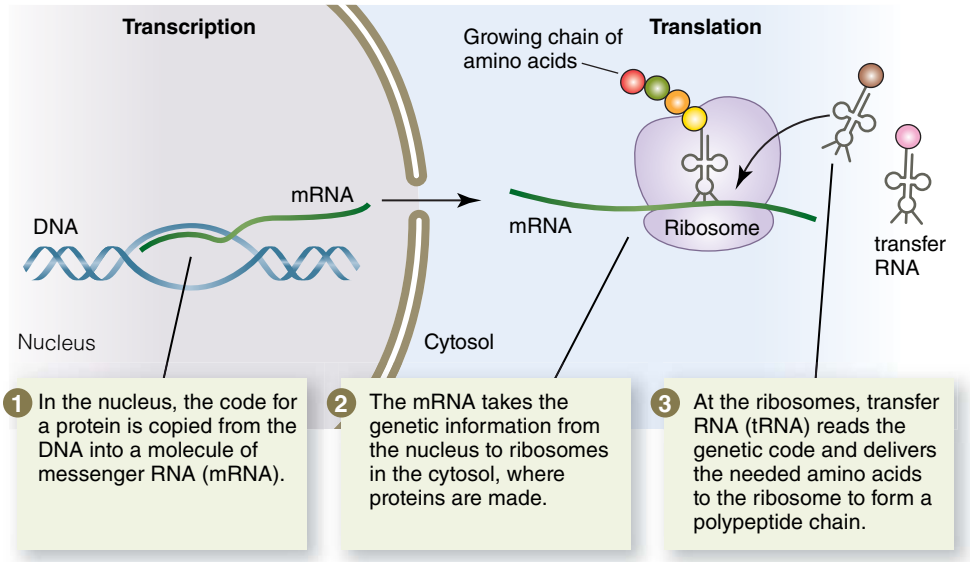


FIGURE 6.9 Transcription and translation
DNA in cell nuclei provides the information needed to assemble a polypeptide chain (transcription and translation).

SCIENCE APPLIED

How Bacteria Created the Field of Biotechnology

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

By using the techniques of genetic engineering, scientists today can create bacteria that make human insulin and plants that synthesize their own insecticide. These techniques can modify the genes in an organism, thus changing the proteins made by that organism. This creates unlimited possibilities for the production of hormones, drugs, and foods that can improve human lives. This technology did not exist before 1970 because we didn't have the "tools" needed to cut DNA. The ability to cut DNA and paste the pieces together emerged from basic laboratory research that studied bacteria.[4]

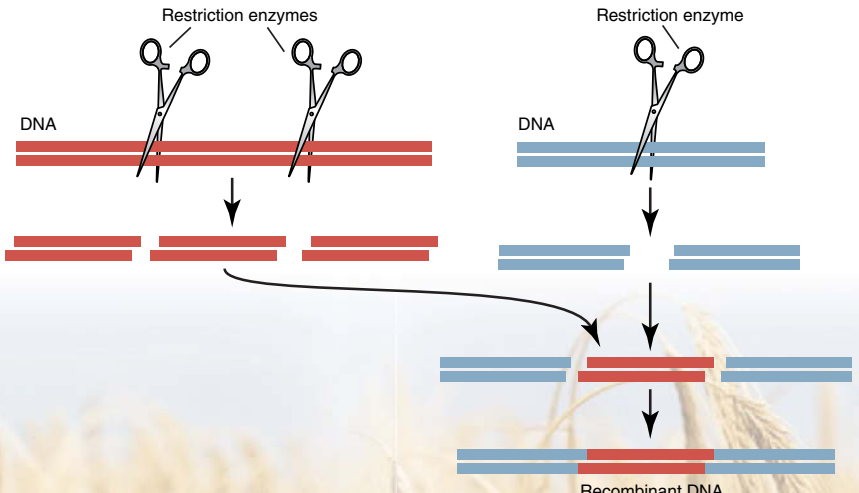
THE SCIENCE

In the 1950s, it was observed that some strains of bacteria were able to slice viral DNA into pieces.[4] This ability was found to be due to bacterial enzymes, called *restriction enzymes*. Restriction enzymes are present in bacteria as a form of protection. If a virus invades the bacterium, it can defend itself by cutting the viral DNA into little pieces before the virus can cause harm. By the late 1960s and early 1970s, restriction enzymes were being isolated and characterized.[5,6] At the same time, bacterial enzymes that repair breaks in DNA, called *DNA ligases*, were also being studied. DNA ligases had the ability to paste together two strands of DNA.

It was hypothesized and confirmed by experimentation that restriction enzymes cut at specific sites on DNA molecules.[6,7] The practical uses for restriction enzymes for the analysis of DNA became apparent in 1971 when Kathleen Danna and Daniel Nathans took a small amount of purified viral DNA, incubated it with a restriction enzyme, and were able to separate the resulting DNA fragments based on their size.[8] Researchers were quick to recognize that restriction enzymes provided them with a remarkable new tool for investigating gene organization, function, and expression. These enzymes could cleave DNA at specific sites, generating gene-size fragments that could then be rejoined in the laboratory. Today, restriction enzymes that cut DNA at more than 250 different specific sequences have been purified and scientists can purchase them from scientific suppliers and use them to locate, isolate, prepare, and study small segments of DNA. At the time restriction enzymes were discovered, their impact on the fields of biology and science was impossible to predict.

THE APPLICATION

In the laboratory, restriction enzymes act like precision scissors that can clip out a gene that codes for a specific protein (see figure). Because DNA in all forms of life is made of the same building blocks, restriction enzymes from bacteria can cut the DNA from a virus, a cow, a soybean plant, or a human cell with equal efficiency. When the gene for a protein produced by a human cell is cut out and pasted into the DNA inside a bacterial cell, the resulting bacterial cells can produce the human protein. These techniques have created an abundant, safe supply of human insulin for the treatment of diabetes, growth hormone for treating children who don't grow because of a growth hormone deficiency, and blood-clotting proteins for treating hemophilia. They have led to new, more powerful cancer therapies and vaccines to prevent disease. Genetic engineering is also changing the foods we eat because genes can be inserted into plant cells. It has created insect-resistant corn, virus-resistant papaya, grains with higher protein quality, and fruits and vegetables with longer shelf life. The discovery and study of these seemingly obscure bacterial enzymes gave rise to the techniques of genetic engineering and the field of biotechnology and will continue to impact science and medicine for years to come (see Focus on Biotechnology).



Restriction enzymes act like "scissors" that cut DNA in specific spots. The restriction enzymes shown here cut a gene from the DNA shown in red, which can be pasted into the DNA shown in blue to form what is referred to as *recombinant DNA*.

changes depending on the need for the proteins for which they code. For example, when zinc intake is high, the expression of a gene that codes for metallothionein, a metal-binding protein, is turned on. This allows more of this protein to be synthesized, increasing the capacity to bind zinc. The levels of nutrients in the body also affect the expression of other genes. For example, vitamin A levels affect the expression of genes involved in the maturation and specialization of cells, and vitamin D affects the expression of genes that code for calcium transport proteins (see Chapter 9).

What Are Limiting Amino Acids? During the synthesis of a protein, a shortage of one needed amino acid can stop the process. Just as on an assembly line, if one part is missing, the line stops—a different part cannot be substituted. If the missing amino acid is a nonessential amino acid, it can be synthesized, most often by transamination, and protein synthesis can continue. If the missing amino acid is an essential amino acid, the body cannot make the amino acid, but it can break down some of its own proteins to obtain it. If an amino acid cannot be supplied, protein synthesis stops.

The essential amino acid present in shortest supply relative to need is called the **limiting amino acid** because lack of this amino acid limits the ability to synthesize the needed protein (Figure 6.10). Proteins from different foods provide different combinations of amino acids, so the limiting amino acids differ in different foods. Animal proteins generally provide enough of all of the amino acids and thus do not limit protein synthesis. Plant proteins are generally low in one or more of the essential amino acids. For example, lysine is the limiting amino acid in rice, whereas methionine is the limiting amino acid in beans. An exception is soy protein, which is as good as animal protein when it comes to supplying essential amino acids. When the combination of foods in the diet provides adequate amounts of all the essential amino acids needed to synthesize a specific protein, synthesis of the polypeptide chains that make up the protein can be completed and the chains can be released for further processing by the cell.

limiting amino acid The essential amino acid that is available in the lowest concentration in relation to the body's needs.

Synthesis of Nonprotein Molecules

Amino acids are needed for the synthesis of a variety of nonprotein molecules that contain nitrogen. For example, the amino acid tryptophan is used to synthesize the neurotransmitter serotonin, which acts in the relaxation center of the brain. Amino acids are also needed for the synthesis of the nitrogen-containing compounds that are the building blocks of DNA and RNA. Other molecules synthesized from amino acids include the skin pigment melanin; the vitamin niacin; creatine, needed to provide energy for muscle contraction; and histamine, which causes blood vessels to dilate.

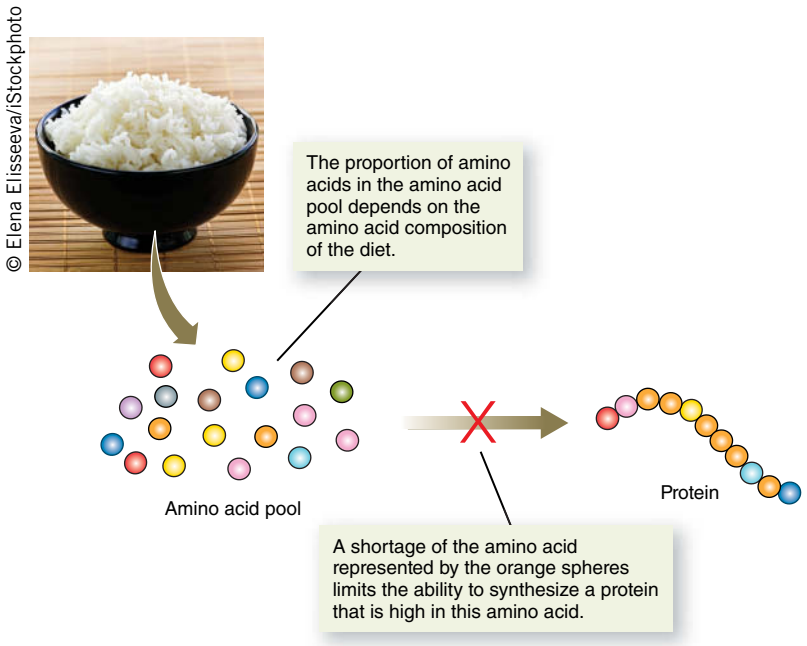


FIGURE 6.10 Limiting amino acids
The amino acids needed for protein synthesis come from the amino acid pool. If the protein to be made needs more of a particular amino acid than is available, that amino acid limits the amount of the protein that can be synthesized, so it is referred to as the limiting amino acid.

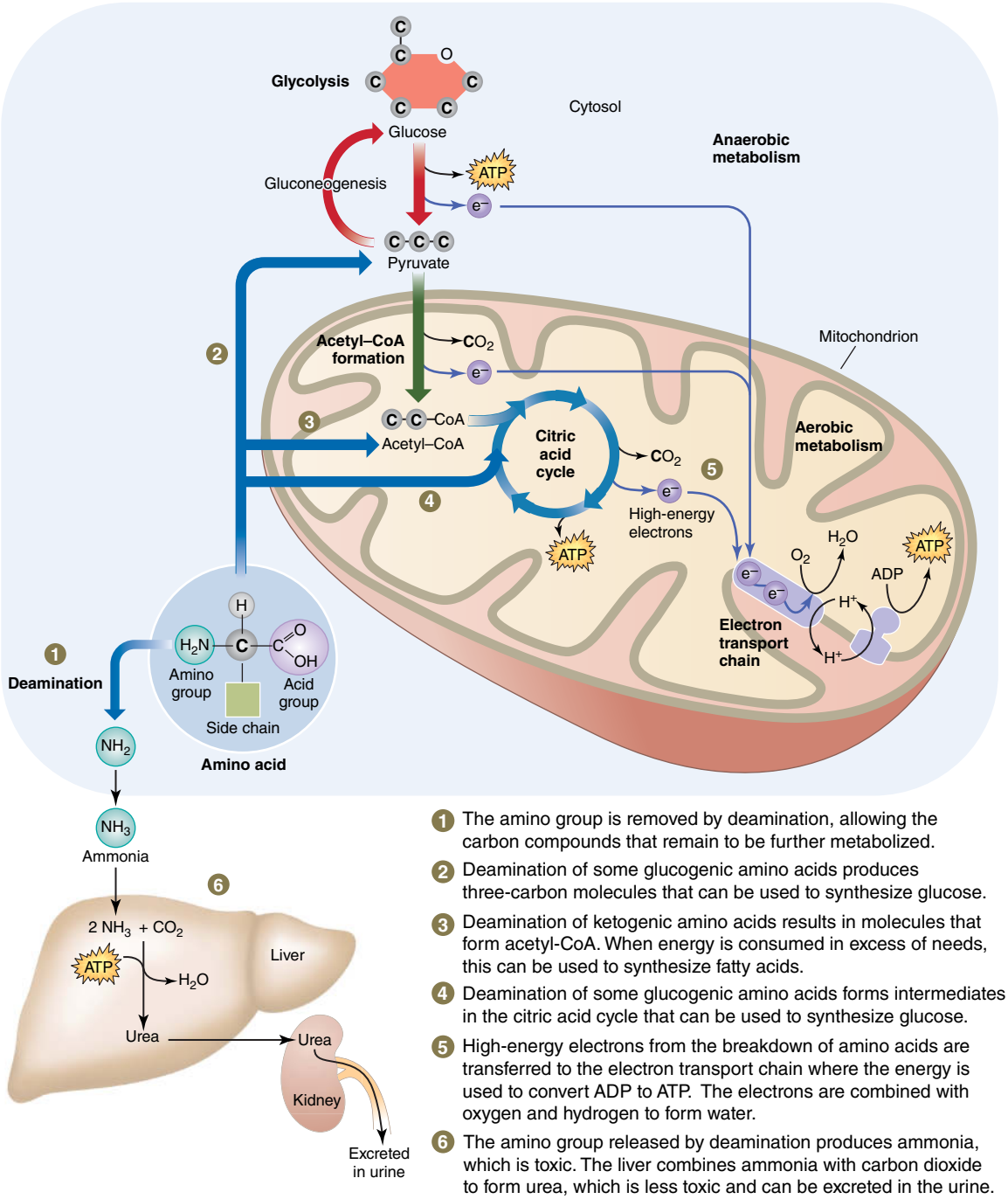
Metabolism

How Amino Acids Provide Energy

Although carbohydrate and fat are more efficient energy sources, amino acids from the diet and from body proteins are also used to provide energy (Figure 6.11). Before this can occur, the nitrogen-containing amino group must be removed from the amino acids in a process called **deamination**. The amino group that is released is converted into **urea** and excreted in the urine. The carbon compounds remaining after deamination can be used in a number of ways, depending on the needs of the body. If energy is needed, the carbon structure of the amino acids can be converted into acetyl-CoA or compounds that directly enter the citric acid cycle to produce ATP (see Figure 6.11). Amino acids that break down to form acetyl-CoA are called ketogenic amino acids (see Chapter 4). Amino acids that break down

deamination The removal of the amino group from an amino acid.

urea A nitrogen-containing waste product formed from the breakdown of amino acids that is excreted in the urine.



1. The amino group is removed by deamination, allowing the carbon compounds that remain to be further metabolized.
2. Deamination of some glucogenic amino acids produces three-carbon molecules that can be used to synthesize glucose.
3. Deamination of ketogenic amino acids results in molecules that form acetyl-CoA. When energy is consumed in excess of needs, this can be used to synthesize fatty acids.
4. Deamination of some glucogenic amino acids forms intermediates in the citric acid cycle that can be used to synthesize glucose.
5. High-energy electrons from the breakdown of amino acids are transferred to the electron transport chain where the energy is used to convert ADP to ATP. The electrons are combined with oxygen and hydrogen to form water.
6. The amino group released by deamination produces ammonia, which is toxic. The liver combines ammonia with carbon dioxide to form urea, which is less toxic and can be excreted in the urine.

FIGURE 6.11 Providing energy from amino acids
In order for the body to use amino acids as an energy source, the nitrogen-containing amino group must be removed. The remaining compounds are composed of carbon, hydrogen, and oxygen and can be broken down to produce ATP.

to form three-carbon compounds or intermediates in the citric acid cycle are called glucogenic amino acids. These can be used by the liver to synthesize glucose via gluconeogenesis. The use of amino acids as an energy source increases both when the diet does not provide enough total energy to meet needs, as in starvation, and when protein is consumed in excess of needs.

When Energy Intake Is Low When energy is deficient, body proteins, such as enzymes and muscle proteins, are broken down into amino acids that can then be used to generate ATP or synthesize glucose. This provides energy in times of need, but it also robs the body of functional proteins. The most dispensable proteins are broken down first, conserving others for the numerous critical roles they play, but if the energy deficit continues, more critical proteins, such as those that make up the heart and other internal organs, will also be degraded. A loss of more than 30% of the body's protein reduces the strength of the muscles required for breathing and heart function, depresses immune function, and causes a general loss of organ function that is great enough to cause death.

When Protein Intake Exceeds Needs Amino acids are used for energy when protein intake exceeds protein needs. If the diet is adequate in energy and high in protein, the amino acids from the excess protein are deaminated and used to produce ATP. If both energy and protein intake exceed needs, the extra amino acids can be converted into acetyl-CoA and used to synthesize fatty acids that can be stored as triglycerides in adipose tissue and can contribute to weight gain.

6.5 Functions of Body Proteins

LEARNING OBJECTIVES

- Give an example of how proteins contribute to body structure.
- Explain why proteins consumed in the diet do not function in the body.
- Describe four types of proteins that help regulate and facilitate body processes.

When you think of the protein in your body, you probably think of muscle, but muscle contains only a few of the more than 500,000 proteins in the human body, each with a specific function. Some perform important structural roles and others help facilitate and regulate specific body processes (Figure 6.12). All the proteins that provide structure and facilitate body activities are synthesized in the body from the amino acids in the amino acid pool.

How Proteins Provide Structure

Proteins provide structure to individual cells and to the body as a whole. In cells, proteins are an integral part of the cell membrane, the cytosol, and the organelles. Skin, hair, and muscle are body structures that are composed largely of protein. The most abundant protein in the body is collagen; it holds cells together and forms the protein framework of bones and teeth. It also forms tendons and ligaments, strengthens artery walls, and is a major constituent of scar tissue. When the diet is deficient in protein, these structures break down. The muscles shrink, the skin loses its elasticity, and the hair becomes thin and can easily be pulled out by the roots.

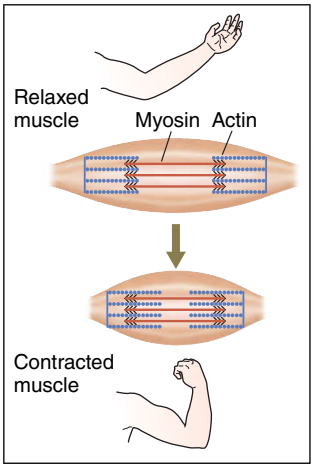
How Proteins Facilitate and Regulate Body Processes

Proteins are the molecules that do most of the body's work. They are necessary for virtually every activity in the body, from promoting chemical reactions and transporting substances into and out of cells to protecting us from disease and allowing us to move (see Figure 6.12).

Enzymes and Protein Hormones Enzymes are protein molecules that speed up metabolic reactions but are not used up or destroyed in the process. Without the help of enzymes, the metabolic reactions that break down molecules to provide energy and build molecules needed by the

FIGURE 6.12 Proteins provide structure and regulation

The protein keratin gives strength to hair. It can be made only inside the body, so a healthy diet will do more for hair quality than expensive protein shampoos.



Proteins help us move. During muscle contraction the proteins actin and myosin slide past each other, causing the muscle fibers to shorten.

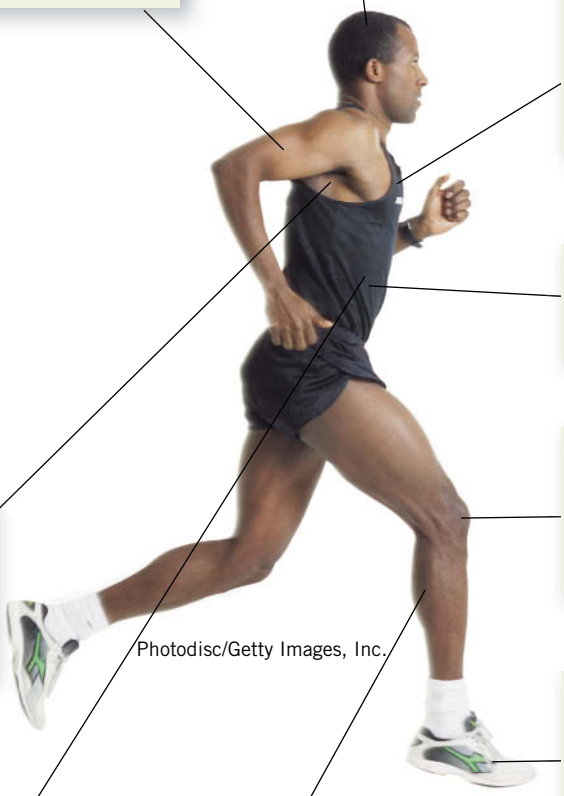
Cheryl Power/Photo Researchers, Inc.

Proteins help transport substances in the body. The protein hemoglobin, which gives red blood cells their color, shuttles oxygen to body cells and carries away carbon dioxide.

ROMEO GACAD/AFP/Getty Images

Some hormones are proteins; insulin and glucagon are protein hormones that help regulate blood sugar.

Antibody proteins help protect us from disease. The vaccination this child is receiving contains dead or inactivated measles virus. It will stimulate the immune system to make antibodies that help destroy the measles virus.



Photodisc/Getty Images, Inc.

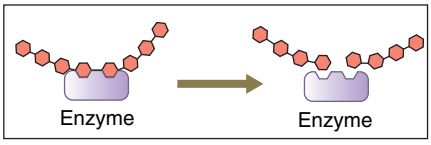
Collagen is the major protein in skin and ligaments. It also gives strength to other tissues and organs and forms the protein framework of bones and teeth.

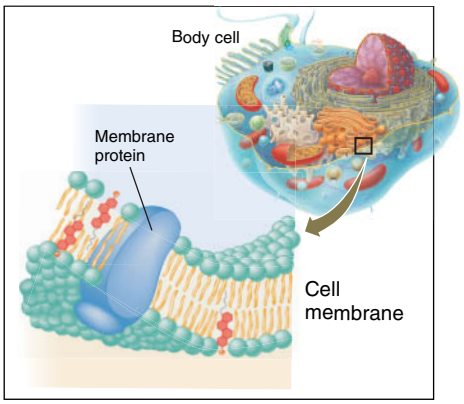
Proteins help regulate fluid balance. If protein levels in the blood fall too low, water leaks out of the blood vessels and accumulates in the tissues, causing swelling known as edema (below).

Almost all the chemical reactions in the body require the help of enzymes, which are proteins. Each enzyme has a unique structure that allows it to interact with the specific molecules in the reaction it accelerates.

Membrane proteins are transporters and receptors. Transport proteins help move amino acids and other molecules into and out of cells, and receptor proteins bind to specific molecules to relay messages.

SPL/Photo Researchers, Inc.





body would occur too slowly to support life. Each of the reactions involved in the production of ATP and the synthesis and breakdown of carbohydrates, lipids, and proteins requires a specific enzyme with a unique structure (see Figure 6.12). If the structure of the enzyme molecule is changed, it can no longer function in the reaction it is designed to accelerate.

Hormones are chemical messengers that are secreted into the blood by one tissue or organ and act on target cells in other parts of the body. Hormones made from amino acids are classified as protein or peptide hormones. For instance, insulin and glucagon are peptide hormones involved in maintaining a steady level of blood glucose. Unlike steroid hormones, which are made from cholesterol and can diffuse across a cell's membrane and into the cell, peptide hormones act by binding to protein receptors on the surface of the cell membrane.

The enzymes and peptide hormones that function in the body are made by the body. When these substances are consumed in food or supplements, they are broken down during digestion and are absorbed from the gastrointestinal tract as amino acids. This is why people with diabetes must inject insulin; taken orally, it would not end up in the bloodstream as insulin. The same is true of enzyme supplements; they are broken down in the gut and do not enter the bloodstream intact. Enzymes intended to function while in the gut can provide function. For example, lactase, taken by individuals with lactose intolerance, remains functional long enough to break down lactose consumed at the same time. Eventually, even digestive enzymes are also digested and absorbed as amino acids.

Transport Proteins Proteins transport substances into and out of individual cells and throughout the body. At the cellular level, transport proteins present in cell membranes help move substances such as glucose and amino acids across the cell membrane into and out of cells. Transport proteins in the blood carry substances from one organ to another (see Figure 6.12). For example, the proteins that form lipoproteins are needed to transport lipids from the intestines and liver to body cells. Some nutrients must be bound to a specific protein to be transported in the blood. When protein is deficient, the nutrients that require proteins for transport cannot travel to the cells. For this reason, a protein deficiency can cause a vitamin A deficiency: Even if vitamin A is consumed in the diet, without protein it cannot be transported to the cells where it is needed.

How Proteins Protect Us Proteins play an important role in protecting the body from injury and invasion by foreign substances. Skin, which is made up primarily of protein, is the first barrier against infection and injury. Foreign particles such as dirt or bacteria that are on intact skin cannot enter the body and can be washed away. If the skin is broken and blood vessels are injured, blood-clotting proteins, including fibrin and thrombin, help prevent too much blood from being lost. If a foreign particle such as a virus or bacterium enters the body, the immune system fights it off by synthesizing proteins called **antibodies**. Each antibody has a unique structure that allows it to attach to a specific invader. When an antibody binds to an invading substance, the production of more of the same type of antibody is stimulated, and other parts of the immune system are signaled to help destroy the invading substance. The next time the same type of invading bacterium or virus enters the body, the immune system is already primed to produce specific antibodies to fight off that particular invader. Immunizations against diseases stimulate the immune system to produce antibodies to the virus or bacterium that causes the disease (see Figure 6.12). When the body comes in contact with the live virus or bacterium, the immune system is already primed, so a large-scale immune system attack is mounted and the infection is prevented. When the immune system malfunctions as a result of protein deficiency, human immunodeficiency virus (HIV) infection, or other causes, the ability to protect the body from infection is compromised.

antibody A protein produced by the body's immune system that recognizes a foreign substance in the body and helps destroy it.

Contractile Proteins The proteins in muscles allow us to move. When you climb a flight of stairs, walk across the room, or run around the block, you are relying on the muscle proteins actin and myosin, which interact to cause muscles to contract. For example, when you do a biceps curl, the muscles in your biceps shorten as the alternating actin and myosin protein fibers slide past one another (see Figure 6.12). Actin and myosin also cause contraction of the heart muscle and the muscles that cause contraction in the digestive tract, blood vessels, and glands. Actin and myosin can also cause contraction in nonmuscle cells. For example, this contraction helps white blood cells change shape and move so they can reach infected tissues in the body.

The energy for contraction comes from ATP, which is derived primarily from the metabolism of carbohydrate and fat.

Proteins That Regulate Fluid Balance The distribution of fluid among body cells, the bloodstream, and the spaces between cells is important for homeostasis. Osmosis causes water to move back and forth across membranes to maintain appropriate concentrations of dissolved substances inside and outside cells and tissues (see Chapter 10). Proteins help regulate this fluid balance in two ways. First, protein pumps located in cell membranes transport substances from one side of a membrane to the other. Second, large protein molecules present in the blood hold fluid in the blood by contributing to the concentration of dissolved particles in the bloodstream. In cases of protein malnutrition, the concentration of these large proteins in the blood decreases, so fluid is no longer held in the blood by osmosis and it accumulates in tissues and in the abdomen (see Figure 6.12).

pH A measure of acidity.

Proteins That Regulate Acid–Base Balance The chemical reactions of metabolism require a specific level of acidity, or **pH**, to function properly. In the gastrointestinal tract, pH varies widely. The digestive enzyme pepsin works best in the acidic environment of the stomach, whereas the pancreatic enzymes operate best in the more neutral environment of the small intestine. Inside the body, the range of optimal pH is much tighter. The acids and bases produced by metabolic reactions must be neutralized in order to prevent changes in pH, which could inhibit life-sustaining metabolic reactions. The lungs and kidneys help maintain a normal pH by eliminating some of these waste products. Proteins both in the blood and within the cells act as buffers to prevent changes in pH. They function by attracting or releasing hydrogen ions. For instance, the protein hemoglobin in red blood cells helps neutralize acid produced when carbon dioxide reacts with water.

Untreated type 1 diabetes is an example of what happens when the amount of acid produced exceeds the ability of the body's proteins and other systems to neutralize it. In type 1 diabetes, the inability to get glucose into cells results in the breakdown of fats and the buildup of ketones, which are acidic. As ketones accumulate, they cause a drop in pH called *ketoacidosis* (see Chapter 4). The acidic pH denatures proteins, which are then unable to perform their functions, resulting in coma and eventually, if not treated, death.

6.6 Protein, Amino Acids, and Health

LEARNING OBJECTIVES

- Compare kwashiorkor with marasmus.
- Explain why protein-energy malnutrition develops more rapidly in young children than in adults.
- Discuss the potential risks associated with a high-protein diet.

protein-energy malnutrition (PEM) A condition characterized by wasting and an increased susceptibility to infection that results from the long-term consumption of insufficient amounts of energy and protein to meet needs.

kwashiorkor A form of protein-energy malnutrition in which only protein is deficient.

marasmus A form of protein-energy malnutrition in which a deficiency of energy in the diet causes severe body wasting.

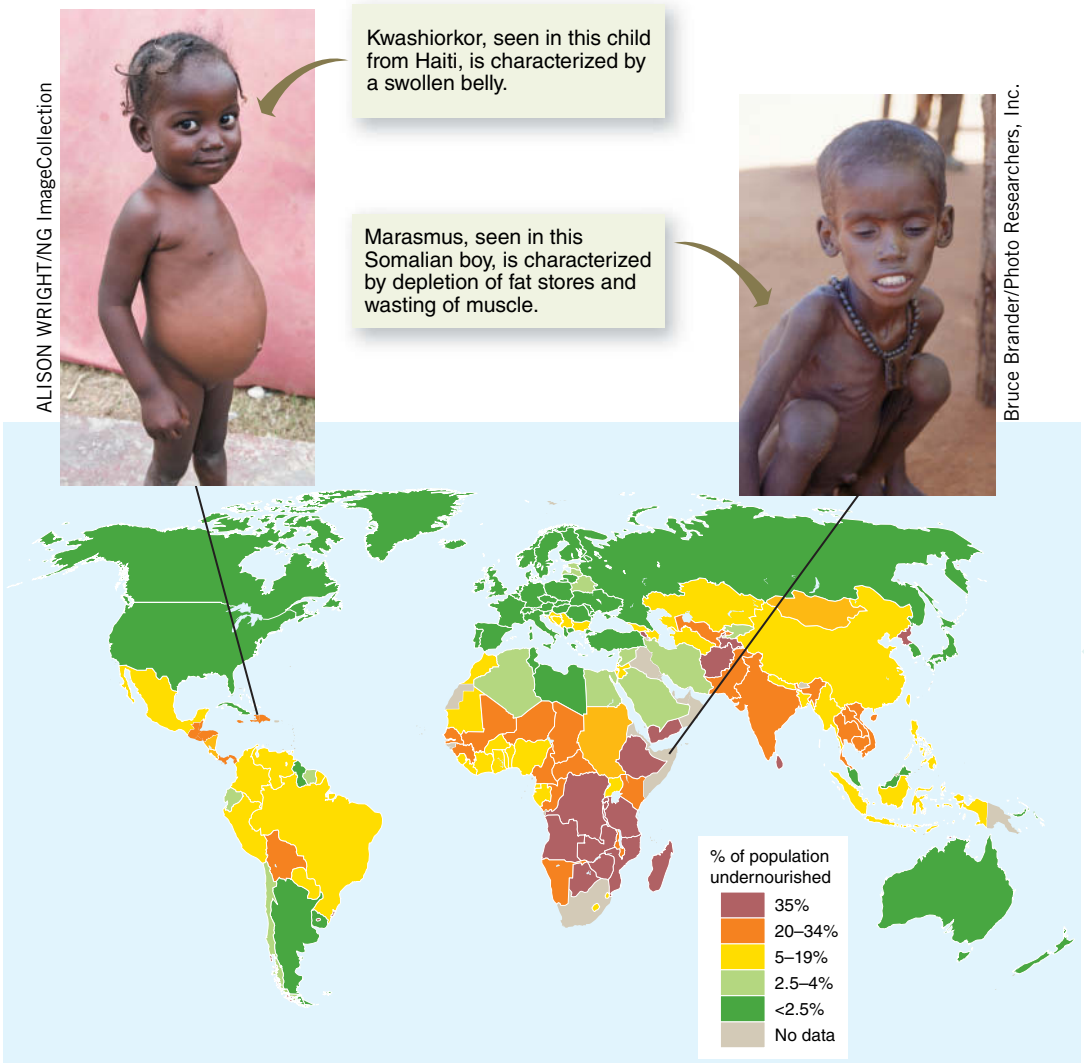
A diet adequate in protein is essential to health. Dietary protein is needed for growth and to replace body protein that is broken down and lost each day. If too little protein is consumed, the consequences can be dramatic and devastating. Too much protein, particularly if it is derived primarily from animal sources, may also have negative health effects. In addition, some people are sensitive to specific proteins and amino acids.

Protein Deficiency

Because of the availability and variety of foods, protein deficiency in developed countries is uncommon. In developing nations, however, concerns about inadequate protein are very real. Usually, protein deficiency occurs along with a general lack of food and other nutrients. The term **protein-energy malnutrition (PEM)** is used to refer to a continuum of conditions ranging from pure protein deficiency, called **kwashiorkor**, to an overall energy deficiency, called **marasmus**. The risks associated with PEM depend on its severity. It is estimated that 40 million children suffer from the most life-threatening form, *severe acute malnutrition (SAM)*; approximately 1 million children with SAM die each year.[9]

Kwashiorkor Kwashiorkor is typically a disease of children. The word *kwashiorkor* comes from the Ga language of coastal Ghana. It means the disease that the first child gets when a second child is born.[10] When the new baby is born, the older child is no longer breast-fed. Rather than receiving protein-rich breast milk, the young child is fed a watered-down version of the diet eaten by the rest of the family. This diet is low in protein and is often high in fiber and difficult to digest. The child, even if able to get adequate energy, is not able to eat a large enough quantity to get adequate protein. Because children are growing, their protein needs per unit of body weight are higher than those of adults, and the effects of a deficiency become evident much more quickly. Although kwashiorkor only occurs in those whose diets are deficient in protein, it is associated with, or even triggered by, infectious diseases and intestinal inflammation. Recent studies suggest that an immature intestinal microbiota may be an important contributing factor in the development of kwashiorkor.[11]

The symptoms of kwashiorkor can be explained by examining the roles that proteins play in the body. Because protein is needed for the synthesis of new tissue, kwashiorkor hampers growth in height and weight in children. Because proteins are important in immune function, children with kwashiorkor are more susceptible to infection. Hair color changes because less of the pigment melanin is made. The skin flakes because structural proteins are not available to provide elasticity and support. Cells lining the digestive tract die and cannot be replaced, so nutrient absorption is impaired. The bloated belly typical of this condition is a result of both fat accumulating in the liver, because there is not enough protein to transport it to other tissues, and fluid accumulating in the abdomen, because there is not enough protein in the blood to keep water from diffusing out of the blood vessels (Figure 6.13).



ANALYZE THE DATA

Which continents have the highest prevalence of PEM?

FIGURE 6.13 Protein-energy malnutrition
Protein-energy malnutrition is uncommon in the United States and other developed nations, but in developing countries, it is a serious public health problem that results in high infant and child mortality.

Kwashiorkor occurs most commonly in Africa, South and Central America, and South Asia. It has also been reported in poverty-stricken areas in the United States. Although kwashiorkor is thought of as a disease of children, it is seen in hospitalized adults who have high-protein needs due to infection or trauma and low-protein intake because they are unable to eat.

Marasmus At the other end of the continuum of protein-energy malnutrition is marasmus, meaning "to waste away." Marasmus is the result of an energy deficiency, but protein and other nutrients are usually also insufficient to meet needs. Marasmus may have some of the same symptoms as kwashiorkor, but there are also differences. In kwashiorkor, some fat stores are retained, since energy intake is adequate. In contrast, individuals with marasmus appear emaciated because their body fat stores have been used to provide energy (see Figure 6.13). Since fat is a major energy source and carbohydrate is limited, ketosis may occur in marasmus. This is not so in kwashiorkor because carbohydrate intake is adequate—only protein is deficient.

Marasmus occurs in individuals of all ages but is most devastating in infants and children because adequate energy is essential for growth. Most brain growth takes place in the first year of life, so malnutrition early in life causes a decrease in intelligence and learning ability that persists throughout life. Marasmus often occurs in children who are fed diluted infant formula prepared by caregivers trying to stretch limited supplies. It occurs less often in breast-fed infants. Marasmus is the form of malnutrition that occurs with eating disorders.

Protein Excess

Adequate protein intake is absolutely essential to life, but too much protein has been hypothesized to affect the health of the kidneys and bones, and to impact the healthfulness of the overall diet. For a healthy person, there are no short-term problems associated with consuming a diet very high in protein, but we are still investigating whether the same is true in the long term (see **Debate: The Highs and Lows of High-Protein Diets**).

Hydration and Kidney Function As protein intake increases above the amount needed, so does the production of protein breakdown products, such as urea, which must be eliminated from the body by the kidneys. To do this, more water must be excreted in the urine, increasing water losses. Although not a concern for most people, this can be a problem if the kidneys are not able to concentrate urine. For example, the immature kidneys of newborn infants are not able to concentrate urine, and therefore infants need to excrete more water than adults to eliminate the same amount of urea. Feeding a newborn infant formula that is too high in protein can increase fluid losses and lead to dehydration. High-protein diets are also a risk for people with kidney disease. The increased wastes produced on a high-protein diet may speed the progression of renal failure in these individuals. There is also some evidence that long-term consumption of a high-protein diet could contribute to the development of kidney disease in people without preexisting kidney disease.[25,26]

Bone Health It has been suggested that the amount and source of protein in the diet affect calcium status and bone health.[27] Adequate protein is essential for healthy bones, but protein intakes above the current RDA have been shown to increase the amount of calcium lost in the urine. Some studies suggest that urinary calcium losses are greater when protein comes from animal rather than vegetable sources.[27] These findings have contributed to a widely held belief that high-protein diets (especially diets that are high in animal protein) result in bone loss. However, it is now recognized that this higher calcium excretion is accompanied by an increase in calcium absorption so there is no net loss of calcium.[28,29] A high-protein intake also causes changes in hormone levels that benefit bone health. Epidemiology and intervention trials indicate that when calcium intake is adequate, high-protein diets are associated with greater bone mass and fewer fractures.[30]

Kidney Stones The increase in urinary calcium excretion associated with high-protein diets has led to speculation that a high-protein intake may increase the risk of kidney stones. Kidney stones are deposits of calcium and other substances in the kidneys and urinary tract. Higher concentrations of calcium and acid in the urine increase the likelihood that the calcium will be

DEBATE

The Highs and Lows of High-Protein Diets

High-protein diets are a popular way to lose weight. But is all that meat good for you? Are such diets effective? And, are they healthy?

What is a high-protein diet? The RDA recommends 0.8 g of protein per kilogram of body weight; for the average American man, who weighs 200 lb, this is 73 g of protein a day; 60 g for the average woman. The typical American diet provides more than this—about 88 g of protein per day or about 16% of calories.[2] So are we all eating high-protein diets? While the typical diet provides more protein than the RDA, it is well within the AMDR of 10 to 35% of calories from protein. Most studies on the effects of high-protein intake consider high protein to be 25% of calories or more from protein. For the average person this is about 134 g/day. This is equivalent to having a 12-oz steak, 3 eggs, and 2 cups of milk every day. Is this diet the best way to lose weight?

Jacek Chabraszewski/Shutterstock

A high-protein diet may include meals such as this one that are based on a large serving of red meat, or they could include fish, poultry, or plant proteins such as legumes.

Weight loss requires consuming fewer calories than you expend, so any diet that limits calorie intake will promote weight loss. Protein is the most satiating of the macronutrients; consequently, high-protein diets do promote weight loss because the protein in the diet keeps you feeling satisfied so you eat less.[12] Protein also affects energy expenditure. When you eat less to lose weight, your metabolism slows to conserve energy. High-protein diets have been found to cause less of a decrease in energy expenditure than low-fat or high-carbohydrate diets.[13,14] Some of this may be because the body uses more calories to process protein than it does for carbohydrate or fat, so eating a high-protein diet increases calorie needs. A high-protein intake also helps maintain the body's muscle mass and the greater one's muscle mass, the greater one's calorie needs. As a result, even people who aren't counting calories may eat less and expend more energy when consuming a high-protein diet than they would with less protein. So, a high-protein diet may be the way to go to lose weight. But, high-protein diets can vary in the amounts of other nutrients. Do the other components of the diet matter?

The amount of carbohydrate in the diet may affect appetite. Some high-protein diets severely restrict carbohydrate. Diets very low in carbohydrate lead to the production of ketones, which further suppress appetite. However, the beneficial effect that a high-protein diet has on weight management has been found to depend on the high-protein, not the "low-carb," component of the diet.[15] Also, severely restricting carbohydrate intake means all but eliminating whole food groups, and may not promote weight loss more than a less restrictive diet.

Does the type of protein you choose matter? A high-protein diet could be high in red meat and high-fat dairy products (see figure), or it could be high in legumes, nuts, fish, and poultry. The source of the protein in the diet, whether plant or animal, does not seem to affect satiety. Plant proteins suppress appetite as well as animal proteins.[16] But the source of the protein may be important for the overall health of the diet.

Many high-protein diets are high in animal products and low in whole grains, fruits, and vegetables; this dietary pattern has been shown to promote heart disease.[17] Despite this, improvements in risk factors for heart disease have been seen in the short term with these diets. An analysis of studies of high-protein diets lasting about six months found small improvements in body fat, blood pressure, and triglyceride levels.[18] Even after a year or more, high-protein diets exerted neither specific beneficial nor detrimental effects on risk factors for heart disease.[19] However, in the long term (an average of about 16 years), some studies find an association between high-protein diets and an increased risk of heart disease and overall mortality.[20,21] Some of the reason for the discrepancy in these results may be the overall dietary pattern; protein sources such as red meat and high-fat dairy products are associated with an elevated risk of coronary heart disease, while higher intakes of poultry, fish, and nuts correlate with a lower risk of coronary heart disease.[22] A dietary pattern that is high in red meat is also associated with an increased risk of cancer, especially colorectal cancer.[23] A study that monitored people for 18 years found that those 50 to 65 years of age who ate a high-protein diet had a 75% increase in overall mortality and a fourfold increase in cancer death risk.[24] These cancer and mortality associations were either abolished or attenuated if the proteins were plant derived.

High-protein diets promote weight loss and weight maintenance and help maintain lean body mass. This is good for your overall health, but if the same diet increases the risk of heart disease and cancer over the long term, is it the best choice?

THINK CRITICALLY: Assume you want to eat a high-protein diet to lose weight. Suggest a meal that provides 40 g of plant-based protein.

OFF THE LABEL

Is It Safe for You?

© iStockphoto

"What is food to one, is to others bitter poison," said the Roman philosopher and scientist Lucretius. Today, fortunately, the information in ingredient lists can help those with food allergies tell the difference. Food manufacturers are required to state clearly if a product contains any of the eight major food allergens: milk, eggs, peanuts, tree nuts, fish, shellfish, soy, and wheat.[34] Products that contain tree nuts also must list the type of nut on the label, and foods containing fish or shellfish must give the species. This information helps quickly identify foods that contain these allergens so they can be avoided.

The information about allergens can be presented on the label in one of three ways. The first is to simply list it clearly in the ingredient list. For example, MILK can be listed with other ingredients. A second way is to use a parenthetical statement. Sometimes this is helpful when listing the actual ingredient is not clear to the consumer. For example, people who are allergic to milk might be allergic to the milk protein casein. They must not only avoid milk and other dairy products, but also foods to which casein has been added. Casein, often listed as sodium caseinate, is used in coffee whiteners and frozen dessert toppings. Foods containing casein can identify it as a milk-derived allergen by using a parenthetical statement, such as CASEIN (MILK).

A third way food labels may indicate the presence of one or more of these eight common allergens is to use the word "contains" followed by the name of the major food allergen printed at the end of the ingredient list or next to it, for example: CONTAINS WHEAT AND SOY INGREDIENTS. This is helpful because some foods are unexpected sources of allergens. For example, isolated soy protein may be added to canned soups or gravies to aid in emulsification or add texture. A person trying to avoid soy would not necessarily think of soup as a soy product, but the statement at the end of the ingredients warns them that this product CONTAINS SOY INGREDIENTS (see figure).

Keep in mind that even a food that lists zero grams of protein in the Nutrition Facts panel may include protein sources in the ingredient list. The amounts may be too small to add a significant amount of protein but can be enough to cause an allergic reaction. For example, small amounts of *protein hydrolysates* or *hydrolyzed proteins*—proteins that have been treated with acid or enzymes to break them down into amino acids and small peptides—are often added as flavorings, flavor enhancers, stabilizers, or thickening agents in foods such as soups and packaged rice and potato products. To help individuals avoid specific proteins, foods containing protein hydrolysates are required to list the source of the hydrolysate—HYDROLYZED CORN PROTEIN in the soup example.

Finally, products that do not intentionally contain any of the major food allergens may provide a special warning if there is a potential for cross-contamination from equipment or foods processed in the same facility. For example, you may see products declaring that they MAY CONTAIN ALMONDS or that they were PROCESSED IN A FACILITY THAT ALSO PROCESSES PEANUTS—a potentially life-saving warning for individuals with peanut allergy, who can have a severe reaction from minute amounts of peanut protein.

The ingredient list includes sources of protein in food as well as sources of hydrolyzed protein (also called protein hydrolysates).

INGREDIENTS: CHICKEN BROTH, CARROTS, COOKED WHITE CHICKEN MEAT (WHITE CHICKEN MEAT, WATER, SALT, SODIUM PHOSPHATE, ISOLATED SOY PROTEIN, MODIFIED CORN STARCH, CORN STARCH, CARRAGEENAN), TOMATOES, WILD RICE, RICE, CELERY. LESS THAN 2% OF: SALT, MONOSODIUM GLUTAMATE, HYDROLYZED CORN PROTEIN, CHICKEN FAT, ONION POWDER, AUTOLYZED YEAST EXTRACT, PARSLEY FLAKES, NATURAL FLAVOR. CONTAINS SOY INGREDIENTS.

Nutrition Facts

Serving Size 1 cup (239g)
Servings Per Container about 2

Amount Per Serving	
Calories 100 Calories from Fat 30	
	% Daily Value*
Total Fat 1.5g	**2%**
Saturated Fat 2g	**10%**
Trans Fat 0g	
Cholesterol 15mg	**5%**
Sodium 850mg	**35%**
Total Carbohydrate 15g	**5%**
Dietary Fiber 1g	**4%**
Sugars 1g	
Protein 7g	

Vitamin A 25% • Vitamin C 0%
Calcium 0% • Iron 2%

*Percent Daily Values (DV) are based on a 2,000 calorie diet.

There is little emphasis on protein in the Nutrition Facts panel. The grams of protein are given, but a % Daily Value for protein is required only on products that make a claim about the product's protein content.

The Nutrition Facts panel lists the grams of protein in a serving the ingredient list tells you which amino acids or protein-containing ingredients have been added to the product.

deposited, forming these stones. Epidemiological studies suggest that diets that are rich in animal protein and low in fluid contribute to the formation of kidney stones.[25,31]

Heart Disease and Cancer Risk Another concern with high-protein diets is related more to the dietary components that accompany animal versus plant proteins. Typically, high-protein diets are also high in animal products, which are high in saturated fat. Diets high in saturated fat are associated with an increased risk of heart disease. When consumed for up to two years, high-protein, low-carbohydrate weight-loss diets do not appear to cause blood lipid patterns that increase the risk of heart disease, but this dietary pattern may increase the risk of heart disease when consumed over a much longer period of time (see *Debate: The Highs and Lows of High-Protein Diets*).[20] Diets high in red meat and processed meats are also associated with a greater risk of colon cancer. This may be due in part to the fact that some high-protein diets are also low in vegetables and fruits, a pattern associated with the disease.[32] Another hypothesis is that the increase in colon cancer seen on such diets is related to their effect on the intestinal microbiota.[33]

Protein and Amino Acid Intolerances

Unlike lipids and carbohydrates, people don't think of protein as contributing to health problems, but for some people, the wrong protein can be harmful. In some cases, this is because a protein in food is recognized and targeted by the immune system, causing an allergic reaction. There are no cures for food allergies so, to avoid symptoms, allergic individuals need to avoid eating foods that contain proteins that cause an allergic reaction (see **Off the Label: Is It Safe for You?**). Not all adverse reactions to proteins and amino acids are due to allergies; some are due to food intolerances, also called food sensitivities. The symptoms of a food intolerance can range from minor discomfort, such as the abdominal distress some people feel after eating raw onions, to more severe reactions.

Why Some People Must Avoid Gluten Gluten-related disorders include celiac disease as well as wheat allergy and non-celiac gluten sensitivity.[35] Individuals with any of these conditions become symptomatic following the consumption of gluten, a protein found in wheat, rye, and barley. The most publicized, **celiac disease**, also known as celiac sprue, or gluten-sensitive enteropathy, is an autoimmune disease in which gluten triggers the immune system to attack the villi in the small intestine, causing symptoms such as diarrhea, abdominal bloating and cramps, weight loss, and anemia. Once thought to be a rare childhood disease, it is now known to affect about 1% of the population in the United States.[36] The only treatment is to avoid gluten by eliminating all products containing gluten from the diet (see Chapter 3, *Debate: Should You Be Gluten Free?*).

celiac disease A disorder that causes damage to the intestines when the protein gluten is eaten.

Why Aspartame Is Dangerous for People with Phenylketonuria Aspartame is a sugar substitute composed of two amino acids, aspartic acid and phenylalanine. Aspartame is used in a wide variety of foods, including carbonated beverages, gelatin desserts, and chewing gum. Digestion breaks aspartame into aspartic acid, phenylalanine, and an alcohol called methanol. Because the phenylalanine released from aspartame digestion is absorbed into the blood, food products containing this nonnutritive sweetener must be avoided by individuals with a genetic disorder called **phenylketonuria (PKU)**.

Individuals with PKU inherit a defective gene for an enzyme called *phenylalanine hydroxylase* that is needed to metabolize phenylalanine. In those with this faulty gene, the enzyme does not function properly, and they are unable to convert the essential amino acid phenylalanine to the semiessential amino acid tyrosine. Instead, phenylalanine is converted to compounds called *phenylketones*, which build up in the blood (Figure 6.14A). In infants and children, high phenylketone levels can interfere with brain development, causing intellectual disability.

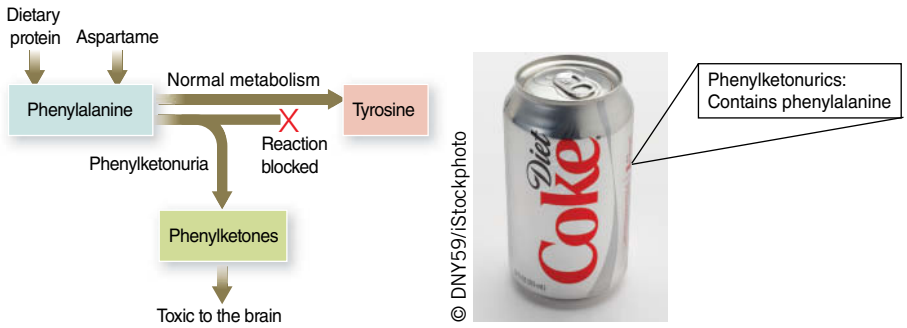
phenylketonuria (PKU) An inherited disease in which the body cannot metabolize the amino acid phenylalanine. If the disease is untreated, toxic by-products called *phenylketones* accumulate in the blood and interfere with brain development.

The incidence of PKU is highest among Caucasians, afflicting about 1 in 10,000 newborn infants.[37] Infants are tested for this disorder at birth because brain damage can be avoided by a special low-phenylalanine diet. Pregnant women with PKU must be especially careful to consume a low-phenylalanine diet in order to protect their unborn children from high phenylketone levels, which can cause brain abnormalities and other birth defects. [38] The diet for people with PKU must provide just enough phenylalanine to meet the body's

THINK CRITICALLY

Why do you think this warning appears on diet soda labels but not on labels for high-protein foods such as meat and milk?

FIGURE 6.14 Phenylketonuria



A. In individuals with phenylketonuria, phenylalanine cannot be converted to tyrosine. Instead, it forms phenylketones, which accumulate and can interfere with brain development.

B. Warnings for individuals with PKU are included on the labels of all products sweetened with aspartame, though few of them specify the actual amount of the sweetener contained in the product.

need for protein synthesis but not so much that the buildup of phenylketones occurs. The diet must also provide sufficient tyrosine because PKU prevents conversion of phenylalanine to tyrosine, causing it to become an essential amino acid. All proteins naturally contain phenylalanine, so a low-phenylalanine diet must carefully regulate overall protein intake. Special low-phenylalanine or phenylalanine-free formulas are manufactured for infants with this disease. Because foods such as diet soda and other aspartame-sweetened beverages do not contain protein, individuals with this disease might not expect them to contain phenylalanine (Figure 6.14B).

Monosodium Glutamate Monosodium glutamate (MSG) is a flavor enhancer best known for its use in Chinese cooking. MSG consists of the amino acid glutamic acid (or glutamate) bound to sodium. In addition to being added to Chinese food, it is used in meat tenderizers, sold as a seasoning, and added to a variety of packaged foods such as potato chips, canned soups, cured meats, and packaged entrees. Some people report adverse reactions including a flushed face, tingling or burning sensations, headache, rapid heartbeat, chest pain, and general weakness after consuming MSG. These symptoms are referred to as *MSG symptom complex*, commonly termed *Chinese restaurant syndrome*. Despite anecdotal reports, research has been unable to confirm that MSG ingestion causes any adverse reactions.[39] Individuals who wish to avoid it can check the ingredient list on packaged foods for monosodium glutamate or potassium glutamate. When eating out, you can avoid this additive by asking the restaurant to prepare your food without added MSG.

6.7 Meeting Recommendations for Protein Intake

LEARNING OBJECTIVES

- Discuss how protein needs are determined.
- Explain what is meant by protein quality.
- Review a diet and substitute complementary plant proteins for the animal proteins it contains.

Protein consumed in the diet must supply amino acids to replace losses that occur during protein turnover, to repair damaged tissues, and to synthesize new body proteins for growth. Current recommendations do not suggest a change in the amount of protein Americans consume, but

do advise varying protein sources by consuming more seafood and vegetable sources of protein.[1] The recommended dietary pattern is based on whole grains, legumes, fruits, and vegetables, with smaller amounts of lean meats and low-fat milk products.

How Protein Requirements Are Determined

Historically, recommendations for protein intake were estimated from the amount of protein consumed by healthy workingmen in the general population. These protein levels were often as high as 150 g/day. Current recommendations are generally lower than this and are based on **nitrogen balance** studies (Figure 6.15). Because protein is the only macronutrient that contains a significant amount of nitrogen, the amount of protein used by the body can be estimated by comparing nitrogen intake with nitrogen loss. Nitrogen intake is calculated from dietary protein intake. Nitrogen loss or output is measured by totaling the amounts of nitrogen excreted in urine and feces and that lost from skin, sweat, hair, and nails. The majority of the nitrogen lost is excreted in the urine as urea (see Figure 6.11). Comparing the amount of nitrogen consumed with the amount lost provides information about the amount of protein being synthesized and broken down within the body. An individual who is consuming enough protein to meet body needs is in protein or nitrogen balance. This means the individual is consuming enough protein to replace the amount that is lost from the body. The protein requirement is the smallest amount of dietary protein that will maintain balance when energy needs are met by carbohydrate and fat.

nitrogen balance The amount of nitrogen consumed in the diet compared with the amount excreted by the body over a given period.

If the body breaks down more protein than it synthesizes, then nitrogen balance is negative; this means more nitrogen is lost than ingested (see Figure 6.15). This indicates that body protein is being lost. Negative nitrogen balance can occur when intake is too low or when the amount of protein breakdown has been increased by a stress such as injury, illness, or surgery.

If the body is synthesizing more protein than it breaks down, nitrogen balance is positive; this indicates that the body is using dietary protein for the synthesis of new body proteins (see Figure 6.15). Positive nitrogen balance occurs when new tissue is synthesized, such as during growth, pregnancy, wound healing, or muscle building.

The protein requirement of a specific individual can be determined by doing a nitrogen balance study for that individual. Because this procedure cannot be done for everyone, the protein needs of populations must be estimated from balance study data. Recommendations for protein

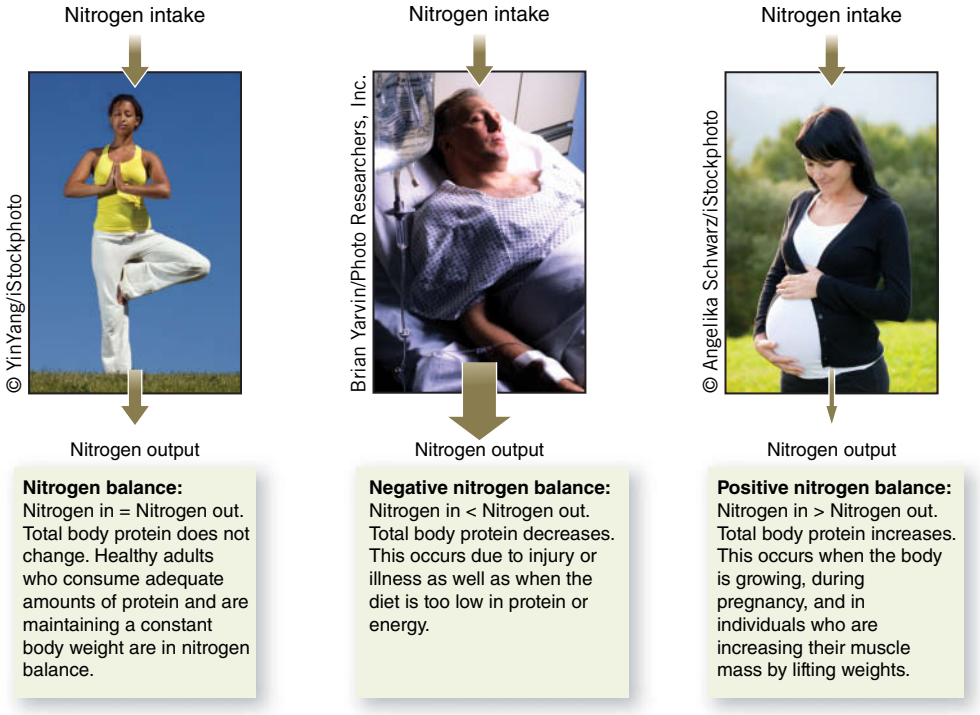


FIGURE 6.15 Nitrogen balance
A comparison of nitrogen intake to nitrogen output can be used to determine whether the body is gaining or losing protein.

THINK CRITICALLY

In someone who is in negative nitrogen balance, nitrogen excretion exceeds nitrogen intake. Where does the extra nitrogen that is excreted come from?

intake for the general population are actually higher than the requirements determined by nitrogen balance studies for individuals. This is to allow a margin of safety that will ensure that the needs of the majority of the population are met.

Protein Recommendations

There are several ways to consider protein recommendations. They can be given as the absolute amount of protein in the diet, the percentage of total calories consumed as protein, and the amount of protein ingested per kilogram of body weight. Regardless of how it is presented, most Americans get plenty of protein.

The RDA for protein is expressed per unit of body weight because protein is needed to maintain and repair the body. The more a person weighs, the more protein he or she needs for those purposes. The RDA for protein for adults is 0.8 g of protein per kilogram of body weight per day.[40] For an adult weighing 70 kg (154 lb), the recommended intake would be 56 g of protein per day (70 kg × 0.8 g/kg/day = 56 g); for an adult weighing 59 kg (130 lb), it would be 47 g/day (59 kg × 0.8 g/kg/day = 47 g). Typical protein intake for adults in the United States is about 88 g/day.[2] Protein needs are increased if protein is being deposited in the body, as it is during growth, or when protein losses are increased, such as during lactation or when the body is injured. RDAs have also been established for each of the essential amino acids (see Appendix A); these are not a concern in a typical diet, but are important when developing intravenous feeding solutions.

The AMDR for protein is 10 to 35% of energy for adults.[40] This range allows for different food preferences and eating patterns. A protein intake in this range will meet needs, balance with carbohydrate and fat calories, and not increase health risks. A diet that provides only 10% of calories from protein meets the RDA, but is a relatively low-protein diet compared with the 16% of energy from protein in the typical U.S. diet.[2] Very few people consume more protein than the upper end of the healthy range—35% of calories. If the proportion of protein goes higher than this, the diet will likely be higher in fat and lower in carbohydrate than is recommended.

iProfile

The amount of protein in a food or in a diet can be estimated from the Choice (Exchange) Lists (Table 6.1) or determined using values from food labels, food composition tables, or iProfile or other diet analysis programs or databases (see online *Nutrient Composition of Foods* supplement).

TABLE 6.1 Using Choice (Exchange) Lists to Estimate Protein Content

Food groups/lists	Serving size	Protein (g)
Carbohydrate group		
Starch	⅓ cup pasta; ½ cup potatoes; 1 slice bread	3
Fruit	1 small apple, peach, pear; ½ banana; ½ cup canned fruit (in juice)	0
Milk	1 cup milk or yogurt	
Nonfat		8
Low-fat		8
Reduced-fat		8
Whole		8
Other carbohydrates	Serving sizes vary	Varies
Vegetables	½ cup cooked vegetables, 1 cup raw	2
Meat/meat substitute group	1 oz meat or cheese; ½ cup legumes	
Very lean		7
Lean		7
Medium-fat		7
High-fat		7
Fat group	1 tsp butter, margarine, or oil; 1 T salad dressing	0

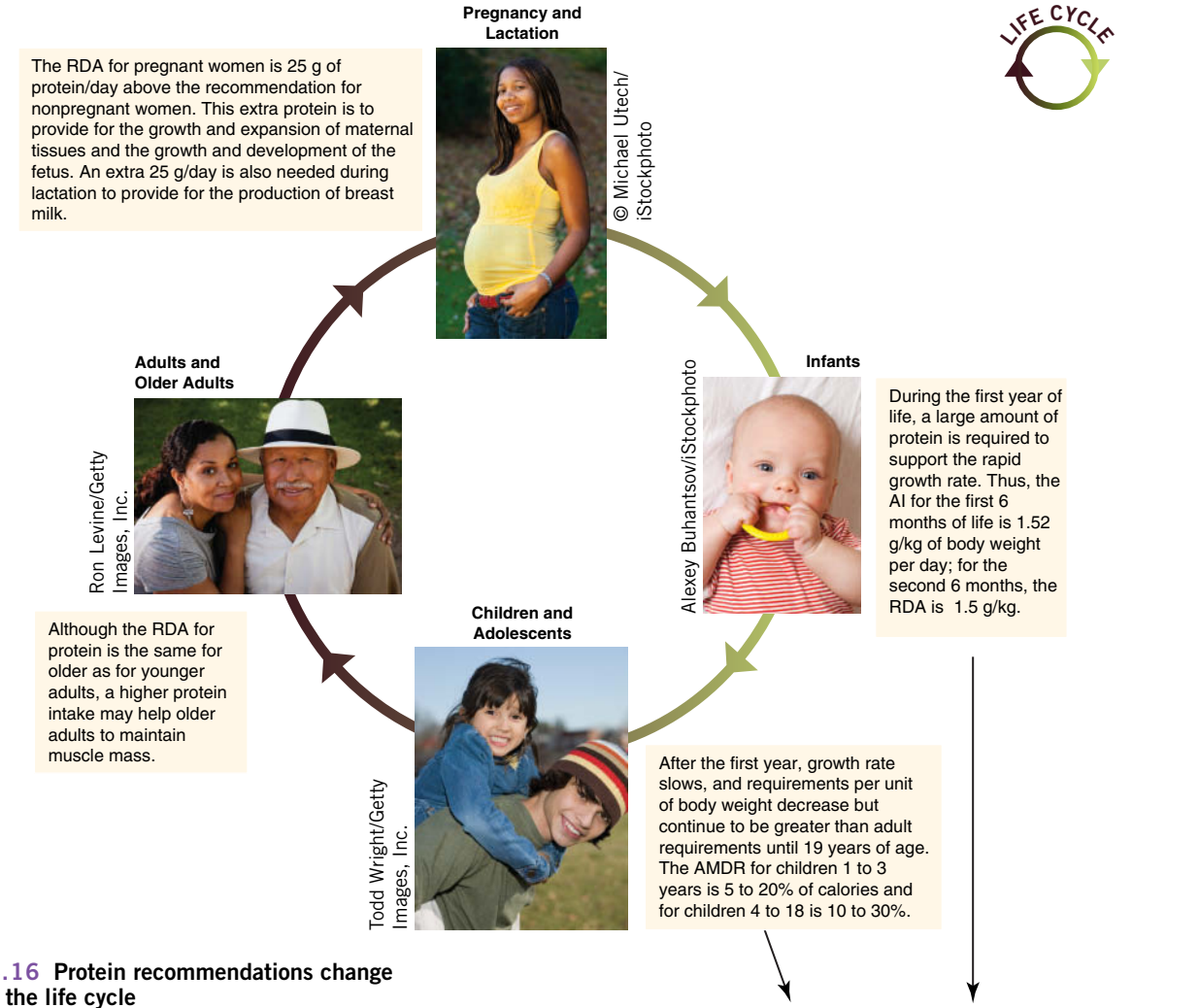


FIGURE 6.16 Protein recommendations change throughout the life cycle

How Protein Needs Change throughout the Life Cycle For an individual to grow, new body proteins must be synthesized. Because infants and children are small, they need less total protein than adults do, but because new protein must be synthesized for growth to occur, protein requirements per unit of body weight are greater than for adults (Figure 6.16). Although the RDA for protein is not increased, recent research suggests that older adults may benefit from increased dietary protein; an intake of 1.0 to 1.2 g/kg of body weight is recommended to compensate for the muscle loss that occurs with aging; higher intakes are recommended for those who are very active or have acute or chronic diseases.[41]

Protein needs are increased during pregnancy and lactation. Additional protein is needed during pregnancy to support the expansion of maternal blood volume, the growth of the uterus and breasts, the formation of the placenta, and the growth and development of the fetus. Additional protein is needed during lactation to support the production and secretion of milk, which is high in protein. Most women in North America already consume enough protein in their typical diets to meet the increased needs of pregnancy and lactation.

Why Protein Needs Are Increased by Illness and Injury Extreme stresses on the body such as infections, fevers, burns, or surgery increase the amount of protein that is broken down. For the body to heal and rebuild, these losses must be replaced by dietary protein. The extra amount needed depends on the injury. A severe infection may increase protein needs by about 30%; a serious burn can increase protein requirements by 200 to 400%.[40]

How Exercise Affects Protein Needs The marketing of protein powders and amino acid supplements to athletes might lead people to believe that protein is in short supply in an athlete's diet. In fact, athletes can obtain plenty of protein in their diets without supplements. Most athletes can meet their protein needs by consuming the RDA of 0.8 g/kg of body weight per day. Only endurance athletes, such as triathletes, and strength athletes, such as body builders, require more than the RDA. Endurance athletes need more protein because some protein is used for energy and to maintain blood glucose during endurance events, such as ultramarathons and long-distance cycling. Athletes participating in endurance events may benefit from 1.2 to 1.4 g of protein per kilogram per day. Strength athletes need extra protein because it provides the raw materials needed for building their large muscles; 1.2 to 1.7 g/kg/day is recommended.[42]

The higher protein needs of endurance and strength athletes can be met without protein supplements as long as the diet provides adequate calories. For example, if a 200-lb (91-kg) man consumes 3600 kcal/day, 16% of which is from protein (approximately the amount contained in a typical North American diet), he will consume 144 g of protein. This equals about 1.6 g of protein per kilogram of body weight. Consuming additional protein as food or supplements will not enhance performance. The protein needs of athletes are also discussed in Chapter 13.

Do We Need Protein and Amino Acid Supplements? Even though protein is plentiful in the American diet, protein and amino acid supplements remain popular among some segments of the population (Figure 6.17). Protein is needed for proper immune function, healthy hair, and muscle growth, but supplements will impact these only if the diet is deficient in protein in the first place. Increasing protein intake above the requirement does not protect you from disease, make your hair shine, or stimulate muscle growth. Although protein supplements are not harmful for most people, they are an expensive and unnecessary way to increase protein intake. If consumed consistently, a high intake of protein from supplements or from foods increases water loss in the urine and may contribute to dehydration and other health problems.

Amino acid supplements are popular among athletes. For instance, the amino acids arginine and ornithine stimulate the release of growth hormone, which promotes muscle growth. Large doses of these amino acids have been shown to stimulate the release of growth hormone, but the effect this has on exercise performance needs further investigation.[43] Branched-chain amino acids (leucine, isoleucine, and valine), arginine, and alanine are also taken to enhance exercise performance. Studies have not shown any of these amino acid supplements to provide a consistent benefit (see Chapter 13).

Translating Recommendations into Healthy Diets

protein quality A measure of how efficiently a protein in the diet can be used to make body proteins.

high-quality or **complete dietary protein** Protein that provides essential amino acids in the proportions needed to support protein synthesis.

To meet protein needs, it is important to consider both the amount and the quality of the protein. **Protein quality** is a measure of how good the protein in a food is at providing the essential amino acids needed by the body. Because animal amino acid patterns are similar to those of humans, the animal proteins in our diet generally provide a mixture of amino acids that better matches our needs than the amino acid mixtures provided by plant proteins. Animal proteins also tend to be digested more easily than plant proteins.[44] Because they are easily digested and supply essential amino acids in the proper proportions for human needs, foods of animal origin are generally sources of **high-quality protein**, or **complete dietary protein**.

FIGURE 6.17 Protein and amino acid supplements Supplements marketed to increase the intake of protein or specific amino acids are expensive and usually unnecessary.

When your diet contains high-quality protein, you don't have to eat as much total protein to meet your needs.

Compared to animal proteins, plant proteins are usually more difficult to digest and most are lower in one or more of the essential amino acids. Exceptions include quinoa and soy protein, which are both high-quality plant proteins. Lower-quality plant proteins are generally referred to as **incomplete dietary proteins**. The RDA for protein is calculated assuming that the diet contains a mixture of plant and animal proteins and therefore is of mixed quality.

incomplete dietary protein Protein that is deficient in one or more essential amino acids relative to body needs.

bioavailability A general term describing how well a nutrient can be absorbed and used by the body.

Measuring Protein Quality

Being able to assess the protein quality of a food or a diet is valuable because it allows us to evaluate the ability of a protein source to meet human protein requirements. Knowing the quality of the protein in cassava, for example, is extremely important in determining the adequacy of the diet in countries where cassava is a staple and both food and protein are scarce.

Protein quality is measured using a number of methods.[45] These measures must consider the amino acid composition of the protein and its **bioavailability**, which refers to the proportion of the amino acids that can be absorbed and used by the body. For over 20 years the *protein digestibility-corrected amino acid score (PDCAAS)* has been considered the best method for evaluating dietary protein quality (Figure 6.18). It is the standard used by the FDA to determine the %Daily Value for protein. Recently however, the Food

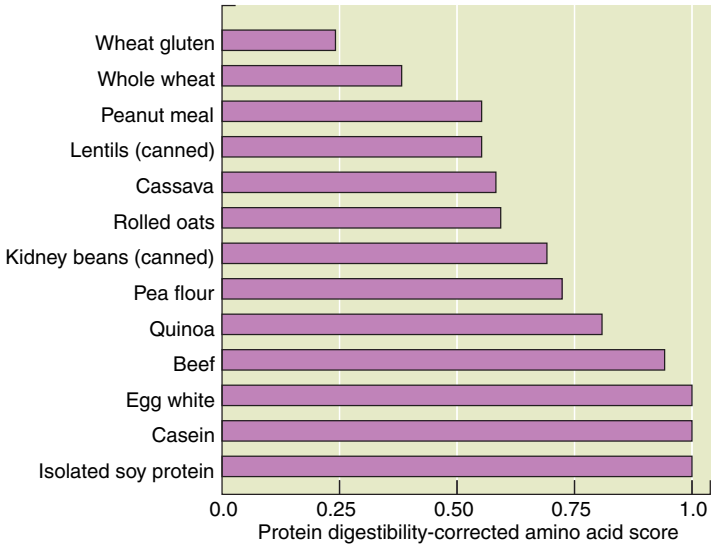


FIGURE 6.18 Comparing protein quality
Protein quality is a measure of how efficiently a protein can be used by the human body. The quality of plant proteins is generally lower than that of animal proteins. An exception is soy protein, which has a PDCAAS of 1.0, the same as egg and milk protein.[47]

Measures of Protein Quality

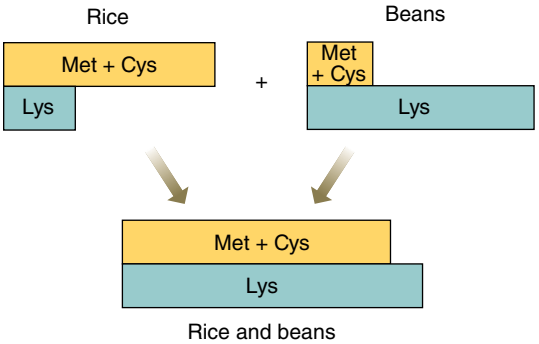
Type of measure	What it is	How it is calculated
Chemical or amino acid score	A measure of protein quality determined by comparing the essential amino acid content of the protein in a food with that in a reference protein. The lowest amino acid ratio calculated is the chemical score.	$= \frac{\text{mg of limiting amino acid/g of test protein}}{\text{mg of limiting amino acid/g of reference protein}} \times 100$
Protein digestibility-corrected amino acid score (PDCAAS)	A measure of protein quality that reflects a protein's digestibility as well as the proportions of amino acids it provides.	$= \frac{\text{amount of limiting amino acid in the test protein}}{\text{amount of that amino acid required by a 2- to 5-yr-old child}} \times \text{protein digestibility}$
Protein efficiency ratio (PER)	A measure of protein quality determined by comparing the weight gain of a laboratory animal fed a test protein with the weight gain of an animal fed a reference protein.	$= \frac{\text{wt gain when fed test protein}}{\text{wt gain when fed reference protein}}$
Net protein utilization (NPU)	A measure of protein quality determined by comparing the amount of nitrogen retained in the body with the amount eaten in the diet.	$= \frac{\text{nitrogen retained}}{\text{nitrogen consumed}} \times 100$
Biological value (BV)	A measure of protein quality determined by comparing the amount of nitrogen retained in the body with the amount absorbed from the diet.	$= \frac{\text{nitrogen retained}}{\text{nitrogen absorbed}} \times 100$

and Agriculture Organization of the United Nations (FAO) endorsed a new method of assessing protein quality, the *digestible indispensable amino acid score (DIAAS)*. This method more correctly assesses bioavailability and provides a more accurate measure of the quality of high-quality proteins and hence their ability to complement other proteins in the diet.[46] Use of the DIAAS cannot be fully implemented until sufficient digestibility data for human foods is available.

Complementary Proteins Assessing protein quality is important in planning diets for regions of the world where protein is scarce. It is less important in industrialized countries, where high-quality protein is readily available to most people. A simpler way of evaluating protein quality in an individual diet is to look at the sources of the protein. As discussed previously, foods of animal origin are sources of complete dietary protein, whereas most plant foods, with the exception of soy and quinoa, contain incomplete proteins. When the diet contains protein from both animal and plant sources, it most likely contains adequate amounts of all the essential amino acids needed for protein synthesis. If the protein in a diet comes only from incomplete sources, **protein complementation** can ensure that protein needs are met.

protein complementation
The process of combining proteins from different sources so that they collectively provide the proportions of amino acids required to meet the body's needs.

Protein complementation combines foods containing proteins with different limiting amino acids in order to improve the protein quality of the diet as a whole. By eating plant proteins with complementary amino acid patterns, essential amino acid requirements can be met without consuming any animal proteins. The amino acids that are most often limited in plant proteins are lysine, methionine, cysteine, and tryptophan. As a general rule, legumes are deficient in methionine and cysteine but high in lysine. Grains, nuts, and seeds are deficient in lysine but high in methionine and cysteine. Corn is deficient in tryptophan as well as lysine but is a good source of methionine. Combining plant foods with complementary proteins provides all of the essential amino acids. For example, consuming rice, which is limited in the amino acid lysine but high in methionine and cysteine, with beans, which are high in lysine but limited in methionine and cysteine, provides enough of all the amino acids needed by the body (Figure 6.19). Plant proteins can also be complemented with animal proteins in order to meet the need for essential amino acids. For example, in Asia rice is often flavored with a small amount of spiced beef, chicken, or fish.



© Timo McIntosh/iStockphoto

FIGURE 6.19 Protein complementation
When rice, which is limited in lysine (Lys) but high in methionine (Met) and cysteine (Cys), is eaten with beans, which are high in Lys but limited in Met and Cys, the combination provides all the amino acids needed by the body. Beans and rice or beans and tortillas are common complementary protein combinations in Central and South America.

Using MyPlate to Make Healthy Choices MyPlate and the Dietary Guidelines include recommendations regarding both animal and plant sources of protein to meet people's need for protein and essential amino acids (Figure 6.20). The MyPlate food groups that provide the most protein per serving are the dairy and protein groups; 1 cup of milk provides about 8 g of protein, 1 oz of meat about 7 g, and ½ cup of beans 7 to 10 g. Each serving from the grains group and the vegetables group provides 2 to 4 g.

Wise choices from the dairy and protein groups, such as low-fat milk, seafood, lean meat and poultry, eggs, legumes, and nuts and seeds, provide plenty of protein and a variety of other nutrients while minimizing saturated fat intake. For example, choosing eggs, lean meats, and skinless chicken provides iron, zinc, vitamin A, and B vitamins. Choosing fat-free or low-fat milk provides calcium, vitamin A, and vitamin D. Increasing consumption of seafood adds iron and zinc and also contributes heart-healthy omega-3 fatty acids. Plant sources of protein bring with them poly- and monounsaturated fats and dietary fiber. Beans, for example, provide about 15 g of fiber per cup. Choosing nuts and seeds from the protein group increases intake of heart-healthy monounsaturated fats and omega-3 fatty acids as well as fiber. Whole grains and vegetables add fiber, phytochemicals, vitamins, and minerals. Each grain and vegetable serving does not provide much protein, but because we eat a larger number of servings from these groups, they make an important contribution to our protein intake.

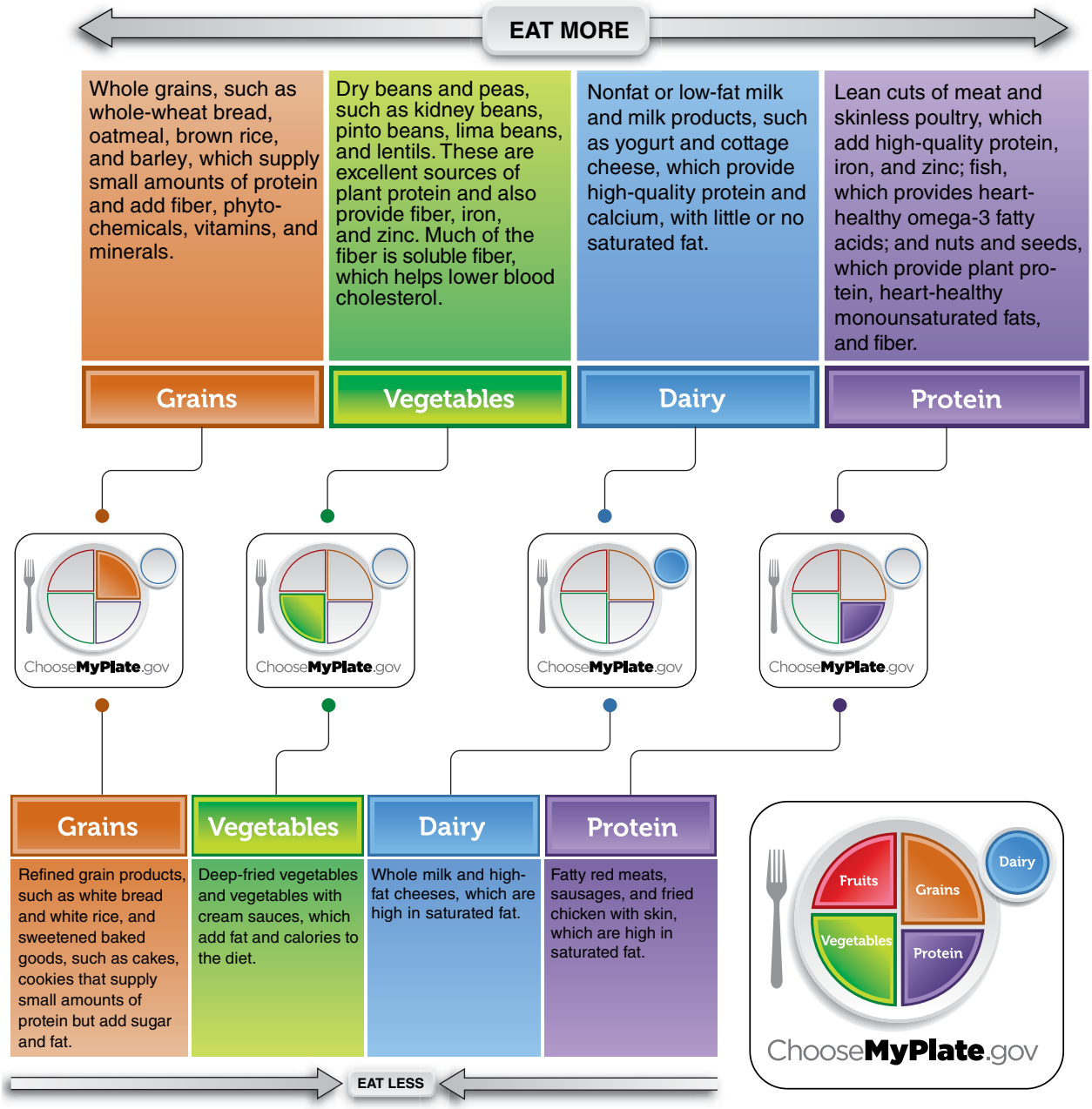


FIGURE 6.20 Choosing healthy protein sources
The protein group and the dairy group provide the most concentrated sources of protein. Nuts, dry beans, and peas are the most concentrated sources of plant protein. When you eat dry beans or peas, you can count them in either the vegetables group or the protein group. The fruit group is not shown here because there is very little protein in fruit.

Using Food Labels to Make Healthy Choices Food labels provide a ready source of information about the protein content of packaged foods, and most fresh meats are required to have a Nutrition Facts label on the package or have the equivalent nutrition information displayed nearby. Labeling of raw fish and seafood, a protein source recommended by the Dietary Guidelines, is voluntary. The Nutrition Facts label lists the number of grams of protein per serving, but the % Daily Value is generally not included. It is required only on labels that carry a claim related to the food's protein content, such as "high protein." The ingredient list provides information on the protein and amino acid–containing ingredients in the food. This information can be important for people with allergies and those trying to avoid certain additives (see *Off the Label: Is It Safe for You?*).

6.8 Vegetarian Diets

LEARNING OBJECTIVES

- Compare the different types of vegetarian diets.
- Discuss the health benefits and nutritional risks of vegetarian diets.

vegetarian diet A pattern of food intake that includes plant-based foods and eliminates some or all foods of animal origin.

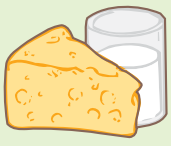
vegan diet A pattern of food intake that eliminates all animal products.

In many parts of the world, diets based on plant proteins, called **vegetarian diets**, have evolved mostly out of necessity because animal sources of protein are limited, either physically or economically, in those areas. Animals require more land and resources to raise and are more expensive to purchase than are plants. In developed countries, people eat vegetarian diets for a variety of reasons other than economics, such as health, religion, personal ethics, or environmental awareness. **Vegan diets** eliminate all animal products, but other vegetarian diet patterns are less restrictive (Table 6.2). About 5% of the adult U.S. population considers themselves vegetarian, and about 2% consumes a vegan diet.[48]

What Are the Benefits of Vegetarian Diets?

A vegetarian diet can be a healthy, low-cost alternative to the traditional American meat-and-potatoes diet. Vegetarians have been shown to have lower body weight relative to height and a

TABLE 6.2 Vegetarian and Nonvegetarian Dietary Patterns

Dietary pattern	Description	Red meat	Poultry/fish	Dairy/eggs
Nonvegetarian	Includes all types of animal products.			
Semivegetarian	Occasional red meat, fish, and poultry, as well as dairy products and eggs.			
Pescetarian	Excludes all animal flesh except fish. Usually includes dairy and eggs.			
Lacto-ovo vegetarian	Excludes all animal flesh but does include eggs and dairy products such as milk and cheese.			
Lacto-vegetarian	Excludes animal flesh and eggs but does include dairy products.			
Vegan	Excludes all food of animal origin.			

reduced incidence of obesity and of other chronic diseases, such as type 2 diabetes, cardiovascular disease, high blood pressure, metabolic syndrome, and some types of cancer.[48] When vegetarians are compared to vegans, vegans have a greater reduction in the risk for obesity, high blood pressure, type 2 diabetes, and cardiovascular mortality.[48] The lower body weight of vegetarians is likely a result of lower energy intake, possibly due to higher intake of fiber, which makes the diet more filling. The reductions in the risk of other chronic diseases may be due to lower body weight and to the fact that these diets are lower in saturated fat. Or it could be that vegetarian diets are higher in whole grains, legumes, nuts, vegetables, and fruits, which add fiber, vitamins, minerals, antioxidants, and phytochemicals—substances that have been shown to lower disease risk. It is likely that the total dietary pattern, rather than a single factor, is responsible for the health-promoting effects of vegetarian diets.

In addition to reducing disease risks, diets that rely more heavily on plant protein than on animal protein are more economical and better for the environment (see Chapter 18). For example, a vegetarian stir-fry over rice costs about half as much as a meal of steak and potatoes, yet both meals provide a significant portion of the day's protein requirement. A small steak, a baked potato with sour cream, and a tossed salad provides about 50 g of protein, whereas a dish of rice with tofu and vegetables provides about 30 g. Dietary patterns that are higher in plant-based foods and lower in animal-based foods are associated with less environmental impact than the current American diet.

Why Some Nutrients Are at Risk of Deficiency in Vegetarian Diets

Despite the health, economic, and environmental benefits of vegetarian diets, a poorly planned vegetarian diet can cause nutrient deficiencies. Protein deficiency is a risk when poorly planned vegan diets that contain little high-quality protein are consumed by small children or by adults with increased protein needs, such as pregnant women and those recovering from illness or injury. Most people can easily meet their protein needs with a well-planned vegan diet (Figure 6.21) or with lacto- or lacto-ovo vegetarian diets, which contain high-quality animal proteins from eggs or milk. The egg and milk proteins complement the limiting amino acids in the plant proteins. It is not necessary to consume complementary proteins at each meal, but the entire day's diet should include proteins from complementary sources in order to satisfy the daily need for amino acids.[49]

Vitamin and mineral deficiencies are a greater concern for vegetarians than is protein deficiency.[49] Of primary concern to vegans is vitamin B_{12}. Because this B vitamin is found almost exclusively in animal products, vegans must take vitamin B_{12} supplements or consume

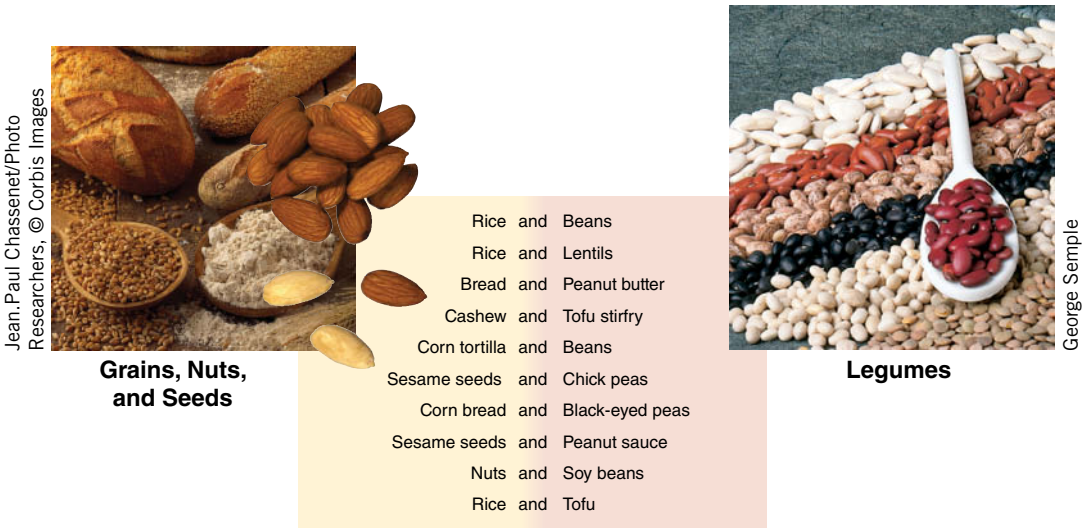


FIGURE 6.21 Combining plant proteins
Combining complementary sources of plant proteins can provide enough of all the essential amino acids, without animal proteins. Grain and legume combinations that have become cultural staples include rice or tortillas and beans in Central and South America, rice and tofu in China and Japan, rice and lentils in India, rice and black-eyed peas in the southern United States, and bread and peanut butter (peanuts are legumes) throughout the United States.

CRITICAL THINKING

Choosing a Healthy Vegetarian Diet

Robyn Mackenzie/iStockphoto

Ajay decided to stop eating meat a year ago. Now that he is taking a nutrition class, he wonders if his vegetarian diet is as healthy as he thought. He is 22 years old, is 5′9″ tall, weighs 154 lb, and gets little exercise. His diet analysis is shown here.

▼

Does Ajay's diet provide enough protein to meet his RDA of 0.8 g of protein per kilogram of body weight?

FOOD	SERVING	ENERGY (kcal)	PROTEIN (g)	FIBER (g)	SAT FAT (g)
Breakfast					
Frosted Flakes	2 cup	320	3	2.7	0
Low-fat milk	1 cup	103	8	0	2
Orange juice	1 cup	112	2	0.5	0
Whole-wheat toast	2 slices	144	6	2.2	0
Butter	2 tsp	68	0	0	5
Lunch					
Cheese pizza (regular crust)	2 slices	542	24	4	10
Potato chips	1 oz	155	2	1.2	3
Cola	12 oz	136	0	0	0
Ice cream sandwich	1	143	3	1	3
Dinner					
Vegetable lasagna	10 oz	400	18	4.8	7
Garlic bread	2 slices	189	4	1.5	1
Green salad	1 cup	22	2	3	0
Salad dressing	2 T	118	0	0.3	2
Ice cream	¾ cup	345	6	0	8
Iced tea	8 oz	90	0	0	0
Total		**2887**	**78**	**21.2**	**41**

▼

How does Ajay's percentage of calories from saturated fat compare with recommendations?How does his fiber intake compare with recommendations?

▼

How does Ajay's intake of fruits and vegetables compare to the recommendations of MyPlate? (*Hint:* Use Food-A-Pedia on the MyPlate website.)

Ajay is shocked by how much saturated fat and how little fiber there is in his vegetarian diet. He decides to replace some of the high-fat dairy products in his diet with complementary plant proteins and to eat more fruits, vegetables, and whole grains.

iProfile Use iProfile to find the protein content of your favorite vegetarian entree.

CRITICAL THINKING QUESTIONS

- **Suggest a lunch to replace the pizza that provides complementary plant proteins and includes at least a serving of whole grains and a cup of vegetables.**
- **If Ajay eliminates all dairy products from his diet, for what nutrients would he be at risk for deficiency?**

TABLE 6.3 Meeting Nutrient Needs with a Vegan Diet[49]

Nutrient at risk	Foods to include in a vegan diet
Protein	Soy-based products, legumes, seeds, nuts, grains, and vegetables
Vitamin B_{12}	Products fortified with vitamin B_{12}, such as soymilk, rice milk,* almond milk,* and breakfast cereals; fortified nutritional yeast; dietary supplements
Calcium	Tofu processed with calcium; calcium-rich vegetables such as broccoli, kale, bok choy, and legumes; products fortified with calcium, such as soymilk, rice milk,* almond milk,* grain products, and orange juice
Vitamin D	Sunshine; products fortified with vitamin D, such as soymilk, rice milk,* almond milk,* breakfast cereals, and margarine
Iron	Legumes, tofu, dark green leafy vegetables, dried fruit, whole grains, iron-fortified grain products (absorption is improved when iron-containing foods are consumed with vitamin C found in citrus fruit, tomatoes, strawberries, and dark green vegetables)
Zinc	Whole grains, wheat germ, legumes, nuts, tofu, and fortified breakfast cereals
Iodine	Iodized salt, sea vegetables (seaweed), and foods grown near the sea
Omega-3 fatty acids	Canola oil, flaxseed and flaxseed oil, soybean oil, walnuts, and sea vegetables (seaweed), which contain fatty acids that can be used to synthesize EPA and DHA; DHA-rich microalgae

*Most rice milk and almond milk products are low in protein (about 1 g/serving) but fortified with vitamin B_{12}, calcium, and vitamin D.

foods fortified with vitamin B_{12} to meet their needs for this nutrient. Another nutrient of concern is calcium. Dairy products are the major source of calcium in the North American diet, so diets that eliminate these foods must rely on plant sources of calcium. Likewise, because much of the dietary vitamin D comes from fortified milk, this vitamin must be made in the body from exposure to sunlight or consumed in other sources. Iron and zinc may be deficient in vegetarian diets because they exclude red meat, which is an excellent source of these minerals, and iron and zinc are poorly absorbed from plant sources. Because dairy products are low in iron and zinc, lacto-ovo and lacto-vegetarians as well as vegans are at risk for deficiencies of these minerals. Vegan diets may also be low in iodine and the omega-3 fatty acids EPA and DHA (see Chapter 5).[49] Diets that do not include fish, eggs, or large amounts of sea vegetables may need to include higher levels of α-linolenic acid to ensure adequate amounts of EPA and DHA. By including flaxseed or flax and canola oil, which are good sources of α-linolenic acid, vegetarians can have a healthy ratio of omega-6 to omega-3 fatty acids and be able to synthesize enough of the longer-chain-length omega-3 fatty acids, EPA and DHA, without consuming animal products. Table 6.3 provides suggestions for how vegans can meet the need for the nutrients just discussed.

How to Plan A Healthy Vegetarian Diet

Well-planned vegetarian diets, including vegan diets, can meet nutrient needs at all stages of the life cycle, from infancy, childhood, and adolescence to early, middle, and late adulthood, and during pregnancy and lactation (see **Critical Thinking: Choosing a Healthy Vegetarian Diet**).[49]

One way to plan a healthy vegetarian diet is to modify the selections from MyPlate. The food choices and recommended amounts from the grains, vegetables, and fruits groups should stay the same for vegetarians. Including a cup of dark green and colorful vegetables daily will help meet iron and calcium needs. The dairy group and the protein group include foods of animal origin. Vegetarians who consume eggs and milk can still choose these foods. Those who avoid all animal foods can choose dry beans, nuts and seeds, and soy products from the protein group. Fortified soymilk can be chosen from the dairy group (Figure 6.22). To obtain adequate vitamin B_{12}, vegans must take supplements or use products fortified with vitamin B_{12}. Obtaining plenty of omega-3 fatty acids from foods such as canola oil, nuts, sea vegetables, and flaxseed ensures adequate synthesis of the long-chain omega-3 fatty acids DHA and EPA.

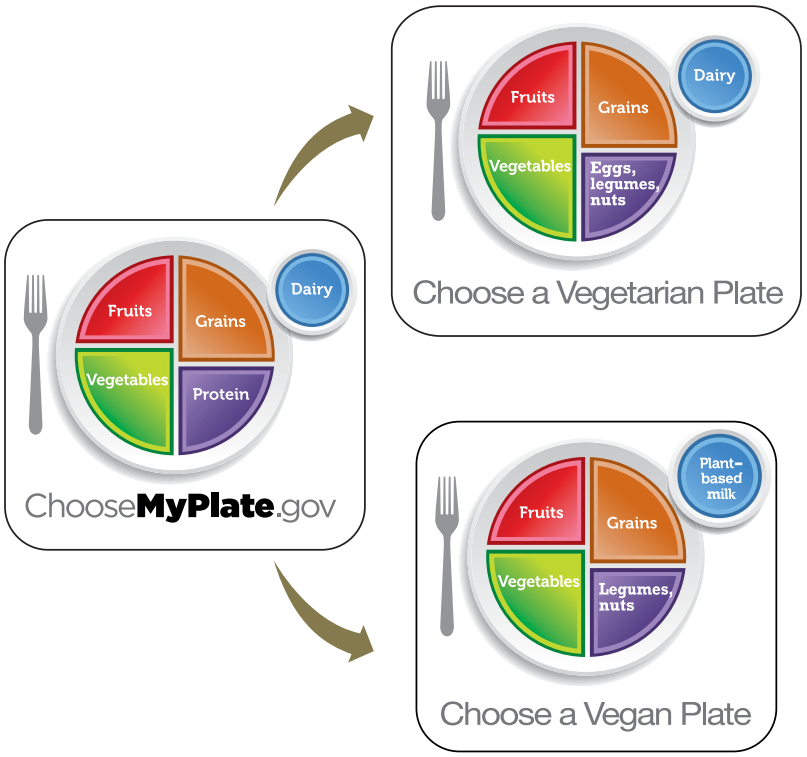


FIGURE 6.22 Using MyPlate to choose a vegetarian dietary pattern MyPlate can be used to choose a healthy vegetarian dietary pattern by making simple modifications to the choices from the protein and dairy groups.

OUTCOME

Elliot did some reading about vegan diets that helped him understand the plant food combinations that would give him enough protein and other nutrients to meet his needs. He now knows that his peanut butter and toast breakfast is an inexpensive source of complementary proteins. He continues to explore the variety of vegan options offered at ethnic restaurants. The Chinese take-out place near campus has a tasty tofu and vegetable stir-fry and the Indian restaurant offers a number of vegan options that contain lentils or chickpeas with rice or naan (a type of Indian bread). At home he eats lots of salads and vegetables with rice. After spending a little extra time at the grocery store, he discovers almond and rice milks in addition to soymilk that are options for his cereal and coffee. He also discovers vegan prepared foods such as veggie burgers and frozen enchiladas. All these choices give him a varied diet that provides plenty of protein, vitamins, and minerals, and has less saturated fat and more fiber than his former diet. **He now knows how to easily find foods that fit in with his vegan diet. He is enjoying his meals and feels good about the health benefits of his diet.**

SUMMARY

6.1 Protein in Our Food

- Dietary protein comes from both animal and plant sources. Most of the protein in the American diet comes from animal foods and we consume more protein than is needed. In developing countries most dietary protein comes from plant sources.
- Animal sources of protein are high in iron, zinc, and calcium but many are also high in saturated fat. Plant sources of protein are rich in fiber, phytochemicals, and monounsaturated and polyunsaturated fats.

6.2 Protein Molecules

- Amino acids consist of a carbon atom with a hydrogen atom, a nitrogen-containing group, an acid group, and a unique side chain attached. The amino acids that the body is unable to make in sufficient amounts are essential amino acids and must be consumed in the diet.
- Proteins are made of amino acid chains that fold over on themselves to create unique three-dimensional structures. The shape of a protein determines its function.

6.3 Protein in the Digestive Tract

- Protein digestion begins in the stomach where acid denatures protein and pepsin breaks polypeptide chains into shorter chains. In the small intestine the remaining polypeptide chains are digested to tripeptides, dipeptides, and amino acids, which are absorbed into the mucosal cell, where dipeptide and tripeptides are broken into single amino acids.
- Amino acids are absorbed into the mucosal cell using one of several active transport systems. Amino acids that share the same transport system compete for absorption.
- In susceptible individuals undigested protein fragments can trigger a food allergy.

6.4 Amino Acid Functions in the Body

- The amino acids in body tissues and fluids that are available for the synthesis of proteins and other nitrogen-containing molecules or for ATP production are known as the amino acid pool; they come from both dietary protein and the degradation of body proteins. The process of continuous breakdown and resynthesis of body proteins is referred to as protein turnover and is necessary for growth, maintenance, and regulation.
- DNA in the nucleus of cells contains the information needed to make body proteins. In transcription, this information is copied into a molecule of mRNA, which carries it to the cytosol. In translation, tRNA translates the mRNA code into a sequence of amino acids. Which genes are expressed determines which proteins are made. If an amino acid needed for protein synthesis is not available, this limiting amino acid can stop protein synthesis.
- Amino acids are used to make nonprotein molecules that contain nitrogen, such as DNA, RNA, and neurotransmitters.
- Amino acids can be used to provide energy when the diet doesn't meet energy needs or when protein intake exceeds needs. Amino acids that are used for energy are first deaminated. The amino groups removed by deamination are converted into urea, which can safely be excreted. The carbon compounds that remain can be broken down to generate ATP or be used to synthesize glucose or fatty acids, depending on the needs of the body.

6.5 Functions of Body Proteins

- Proteins provide structure at the cellular level as an integral component of cell membranes. The proteins in skin, hair, muscle, and connective tissue provide a structural framework for the whole body.
- In the body, proteins facilitate and regulate body functions. Regulatory proteins include enzymes, hormones, transport proteins, antibodies, contractile proteins, and proteins that affect fluid balance and acid balance.

6.6 Protein, Amino Acids, and Health

- Protein-energy malnutrition (PEM) is a concern, primarily in developing countries. Kwashiorkor is a form of PEM that occurs when the protein content of the diet is deficient but energy intake is adequate. It is most common in children. Marasmus is a form of PEM that occurs when total energy intake is deficient.
- High-protein diets increase the production of urea and other waste products that must be excreted in the urine and therefore can increase water losses and the amount of work required by the kidneys. High protein intakes increase urinary calcium losses, but when calcium intake is adequate, high-protein diets are associated with greater bone mass and fewer fractures. Diets high in animal proteins and low in fluid are associated with an increased risk of kidney stones. High-protein diets can be high in saturated fat and over long periods may increase the risk of heart disease and cancer.
- People with food allergies must avoid certain protein sources. Some proteins and amino acids trigger food intolerances. Those with the genetic disease phenylketonuria and sensitivities to gluten must avoid specific foods.

6.7 Meeting Recommendations for Protein Intake

- Protein requirements can be determined using nitrogen balance, which compares the amount of nitrogen consumed in the diet with the amount excreted.
- The RDA for protein for healthy adults is 0.8 g/kg of body weight per day. Healthy diets can include 10 to 35% of energy from protein. Growth, pregnancy, lactation, old age, illness, and injury can increase protein needs. Certain types of physical activity may also increase protein needs. Protein supplements are not needed to meet the protein needs of healthy people.
- Animal proteins contain a pattern of amino acids that matches the needs of the human body more closely than the pattern of amino acids in most plant proteins. Animal proteins are therefore generally of higher quality than plant proteins. Diets that include little or no animal protein can provide adequate protein if the sources of protein are complemented to supply enough of all the essential amino acids.
- MyPlate recommends choosing a variety of protein foods including seafood, lean meat and poultry, eggs, beans, soy products, and unsalted nuts and seeds. Choosing fat-free or low-fat dairy products provides high-quality protein and calcium without much saturated fat.

6.8 Vegetarian Diets

- Many vegetarian diets include some animal products. Vegan diets exclude all foods of animal origin.
- Vegetarian diets are associated with a lower risk for obesity, diabetes, cardiovascular disease, high blood pressure, and some types of cancer.
- Vegetarian diets can easily meet protein needs, but care must be taken to include enough iron and zinc in lacto-ovo vegetarian diets. Well-planned vegan diets can provide adequate amounts of calcium, vitamin D, iron, zinc, and omega-3 fatty acids but must include supplements or fortified foods to meet the need for vitamin B_{12}.

CHAPTER OUTLINE

7.1 Body Weight and Health
- Why Are We Getting Fatter?
- How Excess Body Fat Affects Health
- Health Implications of Being Underweight

7.2 Guidelines for a Healthy Body Weight
- Body Mass Index
- Body Composition
- How Location of Body Fat Affects Health Risk

7.3 Exploring Energy Balance
- Energy In: Calories Consumed in Food
- Energy Out: Calories Used by the Body
- Storing Energy and Using Energy Stores

7.4 Estimating Energy Requirements
- How Energy Expenditure Is Measured
- How to Calculate EER

7.5 What Determines Body Size and Shape?
- Genes versus Environment
- How Food Intake and Body Weight Are Regulated
- Why Some People Gain Weight Easily

7.6 Weight Management
- Who Would Benefit from Weight Loss?
- Weight-Loss Goals
- Why Maintaining Weight Loss Is Challenging
- An Ideal Weight-Management Program
- Managing America's Weight
- Suggestions for Weight Gain

7.7 Approaches to Weight Loss
- Methods to Reduce Energy Intake
- Weight-Loss Drugs and Supplements
- Bariatric Surgery

(©iStockphoto)

© Frank Herholdt / Alamy

Energy Balance and Weight Management

7

CASE STUDY

Spring break was only a week away, and Bethany wanted to take off a few pounds to feel good in a bikini on the beach in Bermuda. She looked on the Internet and found the One-Week All-You-Can Eat Diet. It promised a loss of 5 lb in seven days. She couldn't believe it. She could really eat all she wanted and still lose weight.

The diet did allow her to eat all she wanted, but only of certain foods. On day 1, Bethany was allowed to eat all the fruit she wanted, except bananas. Day 2 was all the vegetables she could eat, as long as they didn't have anything on them but vinegar or soy sauce. On day 3, she could eat all the fruits and vegetables she wanted, but what she really wanted was a big plate of lasagna. By day 4, she got to have milk—five glasses—and five bananas. For the last three days of her diet, she was allowed up to 12 oz of meat and unlimited fresh vegetables. Bethany followed the diet very carefully. It was kind of like eating a different section of MyPlate every day. She got bored with the food choices some days, but there was always something she could eat if she was hungry. She lost 5 lb before she left for Bermuda and felt great her first day in a bikini. To her disappointment, however, by the time the week was over she had regained all the weight she had lost and more. **Bethany had gained 10 lb since the beginning of her freshman year and was hoping that the weight loss she achieved on her one-week crash diet would be permanent.**

Exactostock/SuperStock

7.1 Body Weight and Health

LEARNING OBJECTIVES

- Discuss the increasing incidence of obesity in the United States and throughout the world.
- Describe contemporary lifestyle factors that have contributed to our high incidence of obesity.
- Name some health problems that are common in overweight individuals.
- Discuss the risks associated with being underweight.

overweight Being too heavy for one's height. It is defined as having a body mass index (a ratio of weight to height squared) of 25 to 29.9 kg/m^2.

obese Having excess body fat. Obesity is defined as a body mass index (a ratio of weight to height squared) of 30 kg/m^2 or greater.

In the United States today, a staggering 68.5% (65.8% of women and 71.3% of men) of adults are **overweight** or **obese**.[1] The numbers have increased dramatically during the past five decades. In 1960, only 13.4% of American adults were obese. By 1990, about 23% were obese, and today, less than three decades later, almost 35% are obese (Figure 7.1).[1] Obesity affects both men and women and all racial and ethnic groups. Obesity rates for minorities often exceed those in the general population: Almost 48% of African Americans and over 42% of Hispanic Americans are obese.[1] The problem is not limited to adults. Almost 17% of U.S. children and adolescents ages 2 through 19 are obese.[1] Nor is this problem limited to the United States. Around the world, approximately 1.9 billion adults are overweight, and of these, over 600 million are obese; this is about 13% of the world's adult population.[2] It is such an important trend that the term *globesity* has been coined to reflect the escalation of global obesity and overweight. Once considered problems only in high-income countries, overweight and obesity are now on the rise in low- and middle-income countries, particularly in urban settings.

The repercussions of this rise in obesity have led public health officials to call it an epidemic. Carrying excess body fat is not just a cosmetic concern. It increases the risk of a host of chronic health problems such as diabetes, heart disease, and cancer. It also burdens us financially: The medical care costs of obesity in the United States are estimated to total $147 billion to $190 billion annually.[3]

THINK CRITICALLY

What regions of the United States have the highest obesity rates? Suggest why this might be the case.

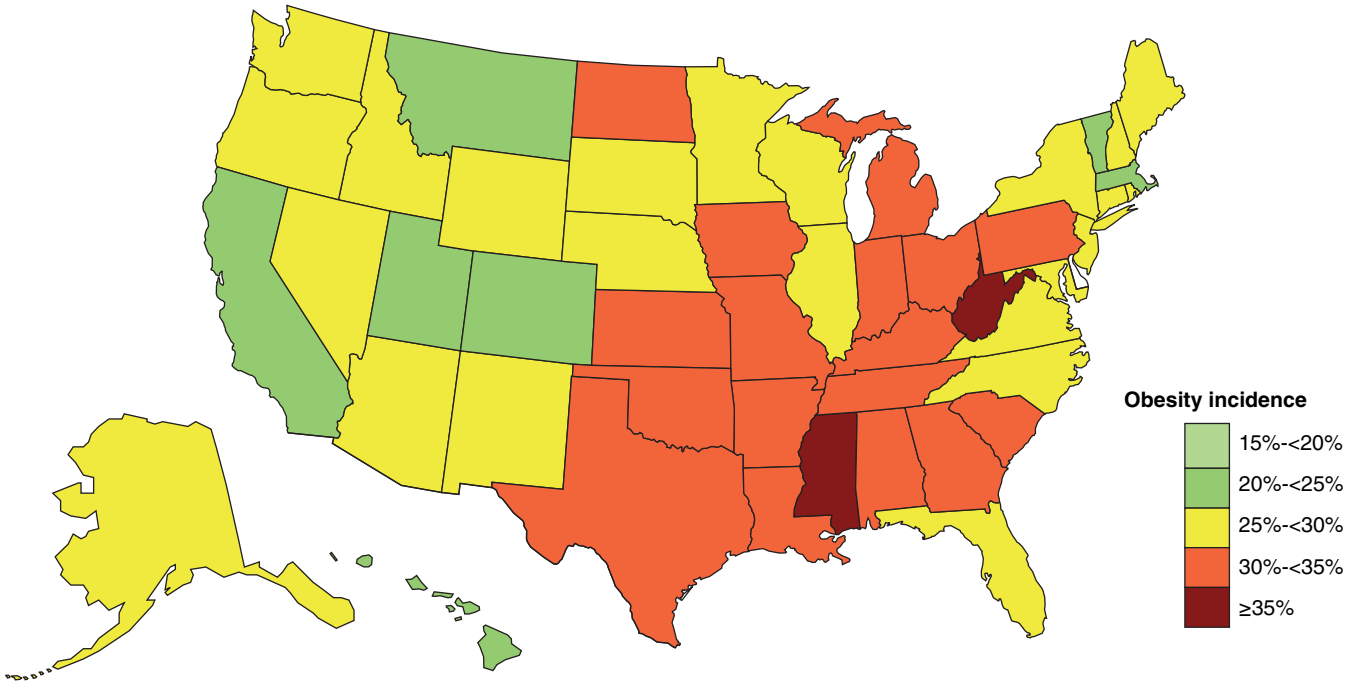


FIGURE 7.1 Incidence of obesity by state
This map shows the percentage of the adult population classified as obese in each state.[4]

Why Are We Getting Fatter?

The reason people are getting fatter is that changes in our food supply and lifestyle have affected what we eat, how much we eat, and how active we are. Simply put, we are overweight because we are eating more and burning fewer calories than we did 50 years ago.[5] Food is plentiful and continuously available, and little activity is required in our daily lives.

Americans Are Eating More In America today, supermarkets, fast-food restaurants, and convenience marts make palatable, affordable food readily available to the majority of the population 24 hours a day. We are constantly bombarded with cues to eat: Advertisements entice us with tasty, inexpensive foods, and convenience stores, food courts, and vending machines tempt us with the sights and smells of fatty, sweet, high-calorie snacks. As a result, since 1970 the amount of energy available to us has increased by about 600 kcal/day, with the greatest increases in added fats, grains, dairy products, and sweeteners.[5] The accessibility of tasty treats stimulates **appetite**. Because appetite is triggered by external cues such as the sight or smell of food, it is usually appetite, and not **hunger**, that makes us stop for an ice cream cone on a summer afternoon or give in to the smell of freshly baked chocolate chip cookies while strolling through the mall. Studies examining the relationship between the food environment and weight have found that a higher frequency of fast-food consumption is associated with a higher body weight and risk of obesity.[6]

appetite A desire to consume specific foods that is independent of hunger.

hunger A desire to consume food that is triggered by internal physiological signals.

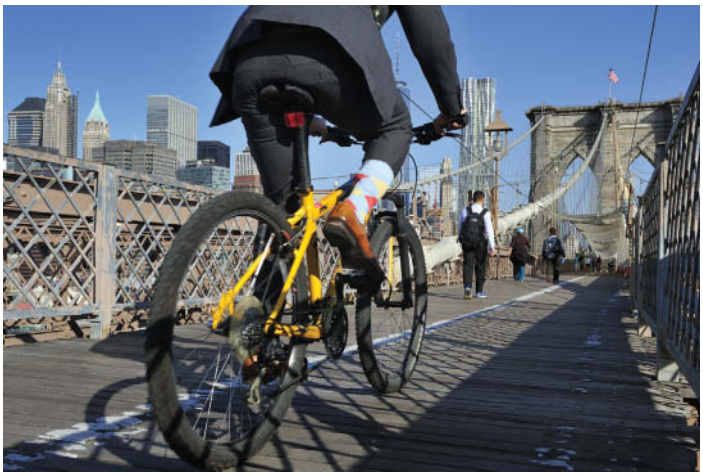
In addition to having more enticing choices available to us, we consume more calories today because portion sizes have increased (Figure 7.2). The more food that is put in front of people, the more they eat.[5] So if you increase the amount of pasta on your plate or cereal in your bowl, you will most likely consume more calories. People tend to eat in units, such as one cookie, one sandwich, or one bag of chips, regardless of the size of the unit. So, when presented with larger units, such as bigger muffins, burgers, or bottles of soda, people still eat or drink the whole thing. As the portions offered have increased, so has the amount Americans consume. You probably wouldn't order an extra hamburger, but you will finish the one you order even if it is the size of two burgers. Portion size is associated with body weight; being served and consuming larger portions are associated with weight gain, whereas small portions are associated with weight loss.[5]

Social changes during the past few decades have also contributed to the increase in the number of calories Americans consume. Busy schedules and an increase in the number of single-parent households and households with two working parents mean that families are often too rushed to cook meals at home. As a result, prepackaged, convenience, and fast-food meals have become mainstays. These foods are typically higher in fat and energy than foods prepared at home.

Americans Are Moving Less Along with America's rising energy intake, there has been a decline in the amount of energy Americans expend, both at work and at play. Fewer American adults today work in jobs that require physical labor. People drive to work rather than walk or bike, take elevators instead of stairs, use dryers rather than hang clothes outside, and cut the lawn with riding mowers rather than with push mowers. All these modern conveniences reduce the amount of energy expended daily (Figure 7.3). Americans are also less active during their leisure time because busy schedules and long days at work and commuting leave little time for active recreation. Instead, at the end of the day, people tend to sit in front of television sets and computers.

Andy Washnik

FIGURE 7.2 Portion distortion
Serving sizes in fast-food restaurants today are much larger than they were when fast food first became popular, about 50 years ago.



T photography/Shutterstock

FIGURE 7.3 Activity reduces the risk of obesity
People who walk or bike to work have greater overall levels of physical activity. When men and women who walked or rode a bicycle to work were compared to their counterparts who drove to work, the more active individuals had a healthier body weight and percentage body fat.[7]

Inactivity is also contributing to excess body weight among children. In the 1960s, schools provided daily physical education classes, and children spent their after-school hours playing outdoors; today, they are more likely to spend their afternoons indoors watching television and playing video games. As a result, they burn fewer calories, snack more, and consequently gain weight.

How Excess Body Fat Affects Health

Some body fat is essential for health, but having too much body fat increases a person's risk of developing a host of obesity-related health problems, also referred to as obesity-related risk factors. These include heart disease, stroke, type 2 diabetes, gallbladder disease, sleep apnea, cancer, arthritis, and reproductive problems (Figure 7.4). Seventy-five percent of those who are obese have at least one obesity-related risk factor.[6] Compared with normal-weight adults, adults who are obese have about a 20% higher risk of dying of all causes.[8] The more excess body fat people have, the greater their health risks. The sedentary lifestyle associated with obesity further increases the risk of diabetes and heart disease and their complications. Being obese also increases the incidence and severity of infectious disease, has been linked to poor wound healing and surgical complications, and increases the risk of psychological and social problems.

Being overweight causes problems throughout life. During pregnancy, carrying excess body fat increases risks both for the mother and her baby (see Chapter 14). In children and adolescents, being overweight contributes to the development of high blood cholesterol levels, high blood pressure, and elevated blood glucose (see Chapter 15). The high rate of childhood obesity is a major threat to this generation because the longer a person is overweight the greater the risks; those who gain excess weight at a young age and remain overweight throughout life have the greatest health risks.

Cardiovascular Disease, Diabetes, and Metabolic Syndrome Obesity increases the overall risk of developing cardiovascular disease because it increases the possibility of developing high blood pressure and abnormal blood lipid levels, and increases the amount of work the heart is required to do. Excess weight contributes to the risk of developing type 2 diabetes because it leads to insulin resistance, which increases the amount of insulin needed to keep blood glucose in the normal range. Over time, the body is no longer able to regulate blood sugar levels, and type 2 diabetes results. Having diabetes, in turn, increases the risks of heart disease and stroke. The term *metabolic syndrome* is used when a cluster of obesity-related risk factors, including high blood lipids, high blood pressure, and high blood sugar, occurs together.

Reducing excess body weight and fat lowers blood pressure, blood cholesterol, and blood glucose levels, and decreases the risk of cardiovascular disease and diabetes. In overweight individuals who have prediabetes or diabetes, weight loss can help bring blood glucose levels into the normal range.[9]

Gallbladder Disease Obesity is associated with an increase in gallstone formation. Gallstones are typically composed primarily of cholesterol and may form as a single large stone or many small ones. They often cause no symptoms, but if they lodge in the bile ducts, gallstones can cause pain and cramps. If the passage of bile is blocked, lipid absorption in the small intestine is impaired and the gallbladder can become inflamed. Often the gallbladder has to be removed to prevent the pain and unblock the duct.

The more obese a person is, the greater his or her risk is of developing gallstones.[10] The reason that obesity increases the risk of gallstones is unclear, but researchers believe that in people who are obese the liver produces too much cholesterol, which deposits in the gallbladder and forms stones. Although the risk of gallstones decreases with a lower body weight, weight loss, in particular rapid weight loss, increases the risk of gallbladder disease because, as lipids are released from body stores, cholesterol synthesis increases, increasing the tendency for

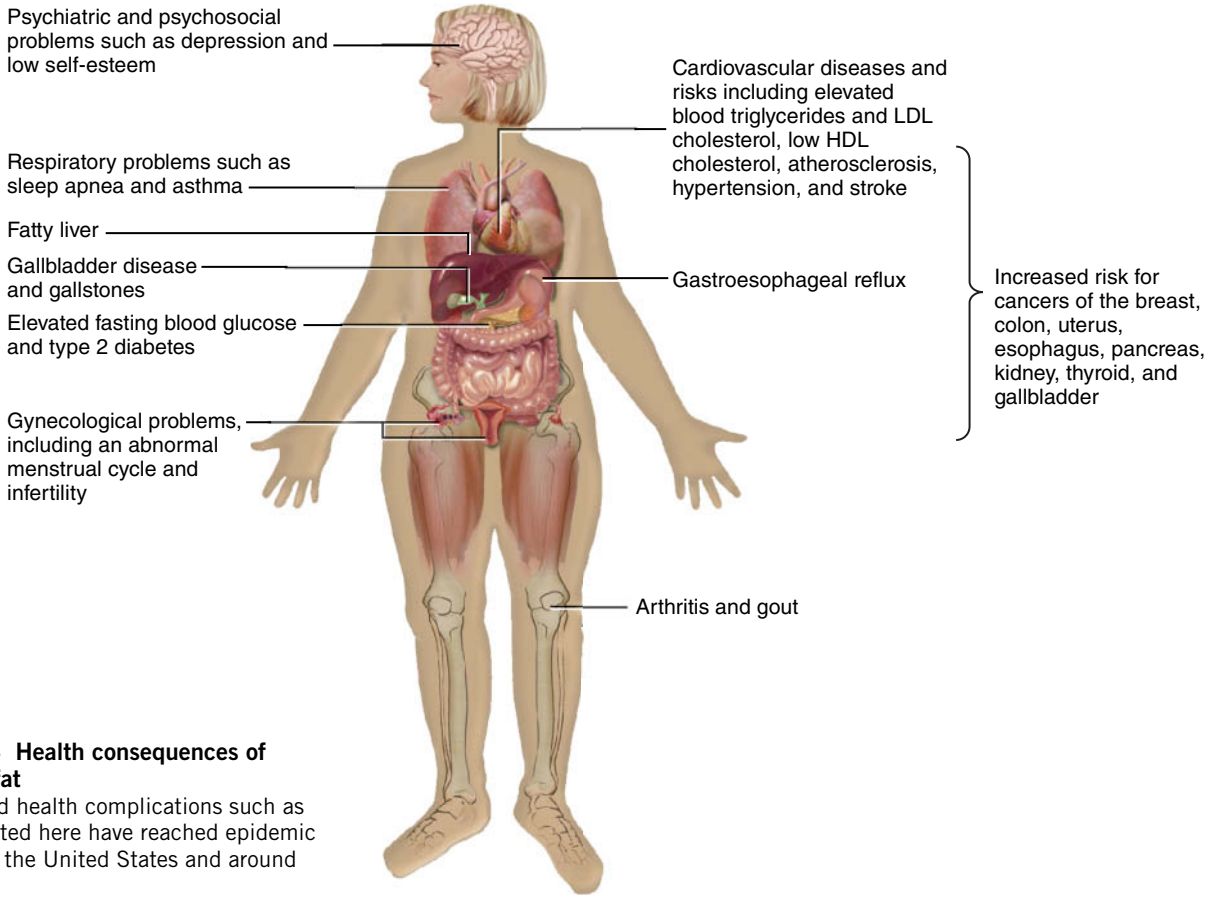


FIGURE 7.4 Health consequences of excess body fat
Obesity-related health complications such as those highlighted here have reached epidemic proportions in the United States and around the world.

cholesterol stone formation. Gallstones are one of the most medically important complications of voluntary weight loss.[10]

Sleep Apnea Sleep apnea is a serious, potentially life-threatening condition characterized by brief interruptions of breathing during sleep. These short stops in breathing can happen up to 400 times every night, and therefore patients with sleep apnea sleep very poorly and wake up in the morning still feeling tired. Sufferers remain tired throughout the day. Sleep apnea has also been associated with other conditions such as high blood pressure, heart attack, stroke, and type 2 diabetes.[11] It is a common complication of obesity because fatty tissue in the pharynx and neck compress the airway and block airflow. In individuals who are obese, weight loss may decrease both the frequency and severity of sleep apnea symptoms.[12]

Cancer Excess body weight and fat are associated with an increased risk of cancers of the esophagus, breast (postmenopausal), uterine lining, colon and rectum, kidney, pancreas, thyroid, gallbladder, and possibly others. It is estimated that if the current obesity trend continues it will lead to an additional 500,000 cases of cancer in the United States by 2030.[13] Several mechanisms have been proposed to explain the association between obesity and various cancers. The greater risk of postmenopausal breast cancer in women who are obese may be due to elevated estrogen levels caused by their excess body fat.[14] Fat cells also produce protein hormones called adipokines. Some of these may contribute to the development of cancer because they promote cell proliferation. Levels of the hormones insulin and insulin-like growth factor, which may promote tumor development, are higher in obese individuals. Adipocytes may also directly or indirectly affect other molecules that regulate tumor growth. Other mechanisms proposed to play a role in the increased cancer risk seen with obesity include inflammation, increased oxidative stress, and altered immune response.[13]

Joint Disorders Excess weight and fat can increase the risk of developing osteoarthritis. This is a type of arthritis that occurs when the cartilage cushioning the joints breaks down and gradually becomes rougher and thinner. As the process continues, a substantial amount of cartilage wears

away, causing the bones in the joints to rub against each other, which results in pain and reduces movement. Being overweight puts excess pressure on the joints and is believed to be a major factor contributing to the increased risk of osteoarthritis. It is now believed that other factors such as disturbances in lipid metabolism, inflammation, and adipokines may also play a role.[15] Losing weight reduces the pressure and strain on the joints and slows the wear and tear of cartilage. Weight loss can help reduce joint pain and stiffness in individuals suffering from osteoarthritis.[16]

Gout is a joint disease caused by high levels of uric acid in the blood. Uric acid is a nitrogenous waste product resulting from the breakdown of DNA and similar types of molecules. It sometimes forms into solid stones or crystal masses that deposit in the joints, causing pain. Gout is more common in overweight people, and the risk of developing the disorder increases with higher body weight.

Psychological and Social Problems Carrying excess body fat has psychological and social consequences. Being thin is considered attractive, whereas being fat is not. Those who do not conform to standards may pay a high psychological and social price. For example, overweight children are often teased and ostracized.[17] Their psychological profile is characterized by low body satisfaction, low self-esteem, depression, and social isolation.[18] If children who are obese continue to be obese as adolescents and adults—as most of them do—they may be discriminated against in college admissions, in the job market, in the workplace, and even on public transportation. Obese individuals of every age are more likely to experience depression, a negative self-image, and feelings of inadequacy.[19] The physical health consequences of obesity may not manifest themselves as disease for years, but the psychological and social problems are felt every day.

Health Implications of Being Underweight

Individuals who have little stored fat also have a greater risk for early death than individuals whose body fat is within the normal range,[20] but this does not mean that all thin people are at risk. People who are naturally lean have a lower incidence of certain chronic diseases and do not face increased health risks due to their low body weight. However, low body fat due to starvation, eating disorders, or disease reduces body fat and muscle mass, affects electrolyte balance, and decreases the ability of the immune system to fight disease.

Too little body fat can cause problems at all stages of life. During adolescence, it can delay sexual development. During pregnancy, too little weight gain increases the risk that the baby will have health complications, and in the elderly, too little body fat increases the risk of malnutrition. In developed countries, socioeconomic conditions may create isolated pockets of undernutrition, but severe cases of wasting are usually a result either of self-starvation due to an eating disorder, such as anorexia nervosa (see Focus on Eating Disorders), or of a disease process, such as acquired immunodeficiency syndrome (AIDS) or cancer.

7.2 Guidelines for a Healthy Body Weight

LEARNING OBJECTIVES

- Calculate your BMI and determine if it is in the healthy range.
- Describe three methods used to estimate percentage of body fat.
- Contrast visceral and subcutaneous fat.

Guidelines for a healthy body weight are based on the weight at which the risks of illness and death are lowest. These risks are associated not only with body weight but also with the amount and location of body fat; therefore, assessment of a healthy body weight must consider body composition.

body mass index (BMI) A measure of body weight in relation to height that is used to compare body size with a standard.

Body Mass Index

The current standard for evaluating body weight is **body mass index (BMI)**, which is calculated from body weight and height. Although BMI does not directly assess body composition, BMI

TABLE 7.1 Is Your BMI in the Healthy Range?[a]

	Underweight		Normal						Overweight					Obese										Extremely obese		
BMI	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Height (ft/in.)	Body weight (lb)																									
4' 10"	81	86	91	96	100	105	110	115	119	124	129	134	138	143	148	153	158	162	167	172	177	181	186	191	198	201
4' 11"	84	89	94	99	104	109	114	119	124	128	133	138	143	148	153	158	163	168	173	178	183	188	193	198	203	208
5' 0"	87	92	97	102	107	112	118	123	128	133	138	143	148	153	158	163	168	174	179	184	189	194	199	204	209	215
5' 1"	90	95	100	106	111	116	122	127	132	137	143	148	153	158	164	169	174	180	185	190	195	201	206	211	217	222
5' 2"	93	98	104	109	115	120	126	131	136	142	147	153	158	164	169	175	180	186	191	196	202	207	213	218	224	229
5' 3"	96	102	107	113	118	124	130	135	141	146	152	158	163	169	175	180	186	191	197	203	208	214	220	225	231	237
5' 4"	99	105	110	116	122	128	134	140	145	151	157	163	169	174	180	186	192	197	204	209	215	221	227	232	238	244
5' 5"	102	108	114	120	126	132	138	144	150	156	162	168	174	180	186	192	198	204	210	216	222	228	234	240	246	252
5' 6"	105	112	118	124	130	136	142	148	155	161	167	173	179	186	192	198	204	210	216	223	229	235	241	247	253	260
5' 7"	108	115	121	127	134	140	146	153	159	166	172	178	185	191	198	204	211	217	223	230	236	242	249	255	261	268
5' 8"	112	119	125	131	138	144	151	158	164	171	177	184	190	197	203	210	216	223	230	236	243	249	256	262	269	276
5' 9"	115	122	128	135	142	149	155	162	169	176	182	189	196	203	209	216	223	230	236	243	250	257	263	270	277	284
5' 10"	119	126	132	139	146	153	160	167	174	181	188	195	202	209	216	222	229	236	243	250	257	264	271	278	285	292
5' 11"	122	129	136	143	150	157	165	172	179	186	193	200	208	215	222	229	236	243	250	257	265	272	279	286	293	301
6' 0"	125	133	140	147	154	162	169	177	184	191	199	206	213	221	228	235	242	250	258	265	272	279	287	294	302	309
6' 1"	129	137	144	151	159	166	174	182	189	197	204	212	219	227	235	242	250	257	265	272	280	288	295	302	310	318
6' 2"	132	140	148	155	163	171	179	186	194	202	210	218	225	233	241	249	256	264	272	280	287	295	303	311	319	326
6' 3"	136	144	152	160	168	176	184	192	200	208	216	224	232	240	248	256	264	272	279	287	295	303	311	319	327	335
6' 4"	140	148	156	164	172	180	189	197	205	213	221	230	238	246	254	263	271	279	287	295	304	312	320	328	336	344

[a]Locate your height in the leftmost column, and read across to your weight. Follow the column containing your weight up to the top line to find your BMI.

values correlate well with the amount of body fat in most people.[21] BMI is calculated from a ratio of weight to height according to either of the following equations:

$$\text{BMI} = \frac{\text{weight (kg)}}{\text{height (m)}^2}$$

or

$$\text{BMI} = \frac{\text{weight (lb)}}{\text{height (in.)}^2} \times 703^*$$

For example, someone who is 6 feet (72 inches [in.] or 1.83 meters [m]) tall and weighs 180 lb (81.8 kg) has a BMI of 24.5 kg/m^2.

What Is a Healthy BMI? A healthy body weight is defined as a BMI of 18.5 to 24.9 kg/m^2. In general, people with a BMI within this range have the lowest health risks. Underweight is defined as a BMI of less than 18.5 kg/m^2, overweight is identified as a BMI of 25 to 29.9 kg/m^2, and obese as a BMI of 30 kg/m^2 or greater. A BMI of 40 or over is classified as extreme or morbid obesity. Table 7.1 can be used to find your BMI and determine whether it is in the healthy range.

Limitations of BMI Even though BMI correlates well with the amount of body fat, it is not a perfect tool for evaluating the health risks associated with obesity. This is because it does not take into account the percentage of body weight that is fat, the type of fat, where the fat is located, or the effect of the fat on health.[22] Because of these limitations, BMI should not be the only measure used to determine nutritional health and fitness. For example, someone who is in the overweight

*The multiplier 703 is used by the Centers for Disease Control and Prevention in developing growth charts, 704.5 is used by the National Institutes of Health, and 700 is used by the Academy of Nutrition and Dietetics. The variation in outcome is insignificant.

Jodi Cobb/NG Image Collection

Joel Sartore/NG Image Collection

FIGURE 7.5 BMI and muscle mass
Both of these men have a BMI of 33, but only the man in the photo on the right has excess body fat. The high body weight of the man in the photo on the left is due to his large muscle mass. The amount of body fat he has and hence his disease risk are low.

category based on BMI but consumes a healthy diet and exercises regularly may be more fit and have a lower risk of chronic disease than someone with a BMI in the healthy range who is sedentary and eats a poor diet.[23]

lean body mass or **fat-free mass** Body mass attributed to nonfat body components such as bone, muscle, and internal organs.

Body Composition

The human body is composed of lean tissue and body fat. Lean tissue, referred to as **lean body mass** or **fat-free mass**, includes bones, muscles, and all tissue except adipose tissue. Adipose tissue lies under the skin and around internal organs. Having excess body fat increases BMI and

FIGURE 7.6 Changes in body composition throughout the life cycle

Pregnancy and Lactation

There is an increase in body fat during pregnancy to provide energy stores for the mother and fetus and to provide energy for lactation.

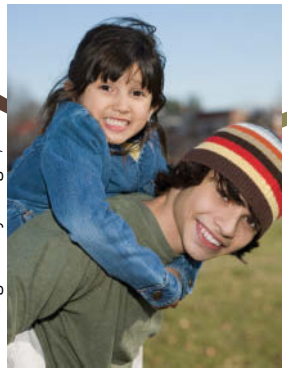
© Michael Utech/iStockphoto

Infants

© Alexey Buhantsov/iStockphoto

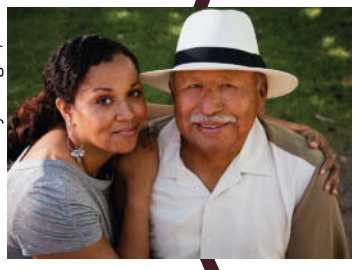
At birth, about 12% of a baby's weight is fat. This percentage increases in the first year of life.

Children and Adolescents


Todd Wright/Getty Images, Inc.

During childhood, as muscle mass increases, the percentage of body fat decreases. During adolescence, girls gain proportionately more fat and boys gain more muscle mass.

Adults and Older Adults


Ron Levine/Getty Images, Inc.

With aging, lean body mass decreases; between the ages of 20 and 60, body fat typically doubles even if body weight remains the same. This occurs regardless of energy intake. Some of this loss of lean body mass can be prevented by strength training.[25]

the risk of cardiovascular disease, type 2 diabetes, and other health problems. Having a large amount of lean tissue also increases BMI, but does not increase health risk. For example, athletes who have highly developed muscles may have a BMI above the healthy body weight range because they have an unusually large amount of lean body mass. In these individuals, BMI is high but body fat and hence disease risk are low (Figure 7.5).

What Is a Healthy Body Composition? The amount of adipose tissue an individual carries and where that fat is deposited are affected by age, gender, and genetics as well as by energy intake and activity level (Figure 7.6). Adult women have more stored body fat than men, so the level that is healthy for women is somewhat higher. A healthy level of body fat for young adult women is between 21 and 32% of total weight; for young adult men, it is between 8 and 19%.[24]

How Body Composition Is Assessed A number of techniques are available for assessing body composition. Many require expensive equipment and must be performed in a research setting by trained technicians. Others are more portable, so they are appropriate for use in a clinic, office, or health club.

Bioelectric Impedance Analysis **Bioelectric impedance analysis** is the most popular way to measure body composition. It estimates body fat by directing a painless, low-energy electrical current through the body. The difference between the current applied to the first electrode and the current that reaches the second electrode is used to determine the resistance, or opposition, to current flow. Lean tissue, which is high in water, conducts electricity, but fat is a poor conductor, so the amount of resistance to current flow is proportional to the amount of body fat. Bioelectric impedance measurements are fast, easy, and painless (Figure 7.7A). However, because impedance is affected by the amount of water in the body, measurements must be performed when the gastrointestinal tract and bladder are empty and body hydration is normal. Measurements performed within 24 hours of strenuous exercise are not accurate because body water is low due to losses in sweat.

bioelectric impedance analysis A technique for estimating body composition that measures body fat by directing a low-energy electric current through the body and calculating resistance to flow.

Skinfold Thickness The use of **skinfold thickness** measurements to assess body composition assumes that the amount of fat under the skin is representative of total body fat. Measurements of the thickness of the layer of **subcutaneous fat** are taken from one or more standard locations using calipers (Figure 7.7B). A nomogram or a mathematical equation is then used to estimate the percentage of body fat from these measurements. Skinfold measurements are noninvasive and, when performed by a trained individual, can accurately predict body fat in normal-weight individuals. These measures are more difficult to perform and less accurate in individuals who are obese or elderly.

skinfold thickness A measurement of subcutaneous fat used to estimate total body fat.

subcutaneous fat Adipose tissue that is located under the skin.

Water and Air Displacement **Underwater weighing** can be used to assess body composition because lean tissue is denser than fat tissue. The difference between a person's weight on land and underwater is used to calculate body volume and body density. Body density is proportional to fat-free mass, so it can be used to determine the amount of body fat. Although this method is accurate and noninvasive, it requires special equipment and cannot be used for some groups, such as small children or frail adults (Figure 7.7C). A newer method for estimating body composition measures air displacement rather than water displacement to determine body volume. The individual is assessed in an air-filled chamber (known as the BOD POD®) rather than in water. It is accurate and more convenient than underwater weighing but expensive and not readily available (Figure 7.7D).[26]

underwater weighing A technique that uses the difference between body weight underwater and body weight on land to estimate body density and calculate body composition.

Dual-Energy X-Ray Absorptiometry Dual-energy X-ray absorptiometry (DXA) is a method that uses two X-ray energies for assessing body composition (Figure 7.7E). A single investigation can accurately determine total body mass, bone mineral mass, and the amount and percentage of body fat.[27] Results can also assess body composition in specific regions of the body. It can be used to evaluate the amount of **visceral fat**, which is associated with the risk of heart disease and other chronic diseases.[27]

visceral fat Adipose tissue that is located in the abdomen around the body's internal organs.

Dilution Methods Body fat can also be assessed by using the principle of dilution. Because water is present primarily in lean tissue and not in fat, a water-soluble isotope can be ingested or injected into the bloodstream and allowed to mix with the water throughout the body. The concentration of the isotope in a sample of body fluid, such as blood, can then be measured. The extent to which the isotope has been diluted can be used to calculate the amount of lean tissue in

FIGURE 7.7 Techniques for measuring body composition

Yoav Levy/Phototake/Alamy

A. Bioelectric impedance devices such as this one can be used to assess body fat by measuring the resistance of body tissues to the flow of electric current.

© Claudio Beduschi/Age Fotostock America, Inc

B. Skinfold thickness calipers are used to measure the thickness of the fat layer under the skin at several locations. The most common sites are the triceps, shown here, and the subscapular area (just below the shoulder blade).

© Yoav Levy/Phototake

C. To measure underwater weight, subjects must sit on a scale, expel the air from their lungs, and be lowered into a tank of water.

Jonathan Kirn/Feature Photo Service/NewsCom

D. The BOD POD® measures the amount of air displaced by the body in a closed chamber. This, along with body weight, is used to determine body density.

NewsCom

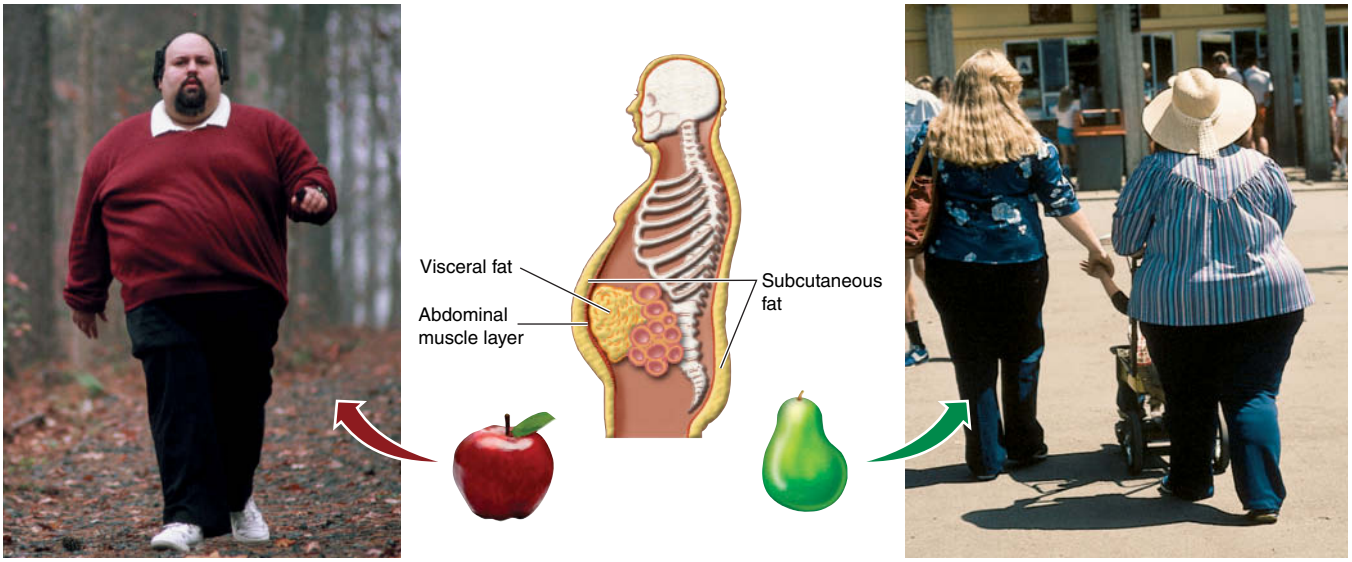
E. DXA distinguishes among various body tissues by measuring differences in levels of X-ray absorption.

the body, and body fat can then be calculated by subtracting lean weight from total body weight. Another technique measures a naturally occurring isotope of potassium. Because potassium is found primarily in lean tissue, a measure of the amount of this isotope in the body can be used to determine the total amount of body potassium, which can then be used to estimate the amount of lean tissue. Dilution techniques are expensive and invasive, usually requiring injections. They are used primarily for research purposes.

How Location of Body Fat Affects Health Risk

The location of body fat stores affects the risks associated with having too much fat (Figure 7.8A). Excess subcutaneous fat does not increase health risk as much as does excess visceral fat. Generally, fat in the hips and lower body is subcutaneous, whereas fat in the abdominal region is primarily visceral. Visceral fat is more metabolically active than subcutaneous fat, releasing dozens of biologically active substances that can contribute to inflammation and disease.[28,29] An increase in visceral

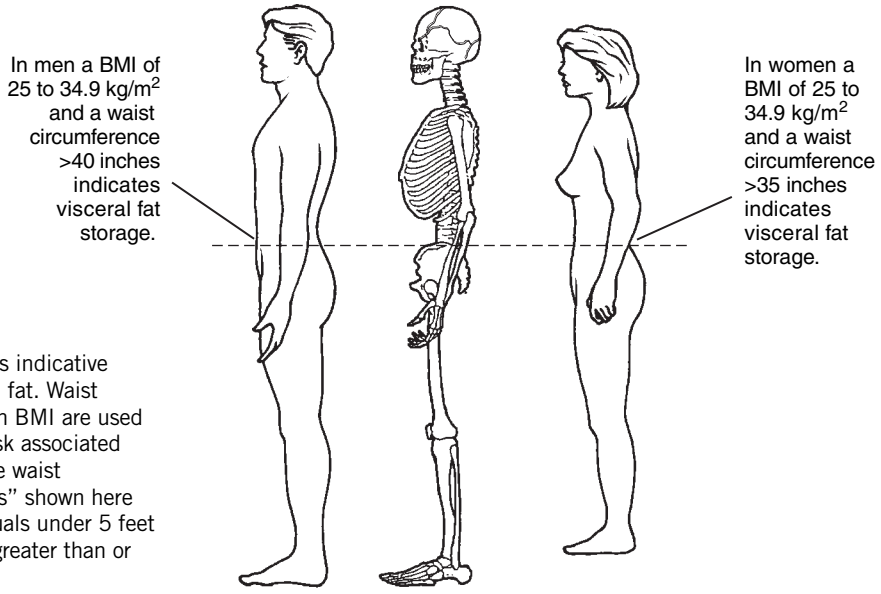
FIGURE 7.8 Visceral and subcutaneous body fat



Annie Griffiths Belt/©Corbis

Tom McHugh/Photo Researchers, Inc.

A. People who carry their excess fat around and above the waist have more visceral fat (left). Those who carry their extra fat below the waist, in the hips and thighs, have more subcutaneous fat (right). In the popular literature, these body types have been dubbed "apples" and "pears," respectively.



B. Waist circumference is indicative of the amount of visceral fat. Waist measurements along with BMI are used to estimate the health risk associated with excess body fat. The waist circumference "cutpoints" shown here are not useful in individuals under 5 feet in height or with a BMI greater than or equal to 35 kg/m^2.

fat is characteristic of metabolic syndrome and is associated with a higher incidence of abnormal blood lipid levels, atherosclerosis, high blood pressure, stroke, insulin resistance and type 2 diabetes, certain types of cancer, and sleep apnea.[29]

Where your extra fat is deposited is determined primarily by your genes.[29] If your parents store fat viscerally, you probably do too. African Americans tend to store less visceral fat than Caucasians of the same age and level of total body fat, whereas Asians are more prone to visceral fat accumulation.[29] Gender, age, and lifestyle also affect visceral fat storage. Visceral fat accumulation is more common in men than women. The amount of visceral adipose tissue increases with age in both men and women. The increase in women is particularly significant after menopause; postmenopausal women have about twice the amount of visceral adipose tissue as premenopausal women.[29] Lifestyle factors that affect the amount of visceral fat include stress, tobacco use, and alcohol consumption, all of which predispose people to visceral fat deposition, and physical activity, which reduces it.

Distinguishing the relative amounts of visceral and subcutaneous fat requires sophisticated imaging techniques. However, the risk associated with visceral fat deposition can be estimated by measuring waist circumference. For men whose BMI is greater than 25 kg/m^2, a waist circumference greater than 40 in. is associated with an increased risk (Figure 7.8B). For women in this BMI range, a waist circumference of greater than 35 in. increases risk.[21]

7.3 Exploring Energy Balance

LEARNING OBJECTIVES

- Explain the principle of energy balance.
- Describe the processes involved in generating ATP from food.
- Describe the components of energy expenditure.
- Explain how excess energy consumed in the diet is stored in the body.

energy balance The amount of energy consumed in the diet compared with the amount expended by the body over a given period.

The principle of **energy balance** states that when energy consumption equals energy expenditure, body weight remains constant. Energy balance can be achieved at any weight—fat, thin, or in between (Figure 7.9); it simply means that body weight is not changing. If, however, the amount of energy taken in exceeds the amount expended, energy balance is positive and the extra energy will be stored in the body, causing weight to increase. On the other hand, if less energy is taken in than expended, energy balance is negative and weight will be lost.

Energy In: Calories Consumed in Food

The energy taken into the body comes from the energy-yielding nutrients (carbohydrates, fats, and proteins) and alcohol consumed in food and beverages. Individuals who struggle with weight loss often think of the calories in food as an enemy—something to be avoided. However, food and the energy it provides are essential for life. Just as gasoline is necessary to run an engine, the energy in food is necessary to run the body. The amount of energy (number of calories) taken in depends on the total amount of food consumed and the nutrient composition of that food. The energy content of food can be measured precisely in the laboratory or estimated from its nutrient composition.

bomb calorimeter An instrument used to determine the energy content of food. It measures the heat energy released when a dried food is combusted.

How the Amount of Energy in Food Is Determined The amount of energy in a food or a mixture of foods can be determined in the laboratory using a **bomb calorimeter**. A bomb calorimeter consists of a chamber surrounded by a jacket of water (Figure 7.10). Food is dried, placed in the chamber, and burned. As the food combusts, heat is released, raising the temperature of the water. The increase in water temperature can be used to calculate the amount of energy in the food based on the fact that 1 kcal is the amount of heat needed to increase the temperature of 1 kg of water by 1 degree Celsius.

THINK CRITICALLY

If you increase the amount of exercise you get, what happens to your energy needs?

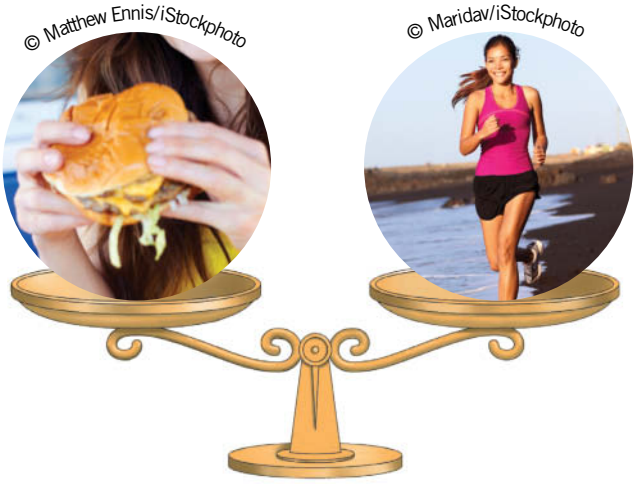


FIGURE 7.9 Energy balance Maintaining your weight requires a balance between how much energy you consume and how much energy you expend.

Combusting a food in a bomb calorimeter determines the total amount of energy contained in that food. However, because the body cannot completely digest, absorb, and utilize all of the substances in a food, bomb calorimeter values are slightly higher than the amount of energy the body can obtain from that food. To correct for this difference, feeding experiments have been done to measure the amount of energy that is not available to the body, such as that lost in urine and feces. Subtracting this unavailable energy from the values determined in the bomb calorimeter gives a more accurate estimate of the energy obtained from food. These types of experiments were used to determine the amount of energy provided by the carbohydrate (4 kcal/g), fat (9 kcal/g), protein (4 kcal/g), and alcohol (7 kcal/g) present in a mixed diet.

When the nutrient composition of a food is known, the energy content of the food can be calculated by totaling the energy from the grams of carbohydrate, fat, protein, and alcohol in the food (Figure 7.11). Vitamins, minerals, and water, though essential nutrients, do not provide energy to the body.

Information about the energy content of foods can be found on food labels and in food composition tables and databases such as iProfile. The Nutrition Facts portion of food labels lists the total calories in a serving of food (see **Off the Label: How Many Calories in That Bowl, Box, or Bottle?**).

The energy content of foods in a diet can also be estimated from the Choice (Exchange) Lists shown in Table 7.2. For example, one starch exchange, whether a slice of bread, ½ cup (100 g) of cereal, or six saltines, provides about 80 kcal.

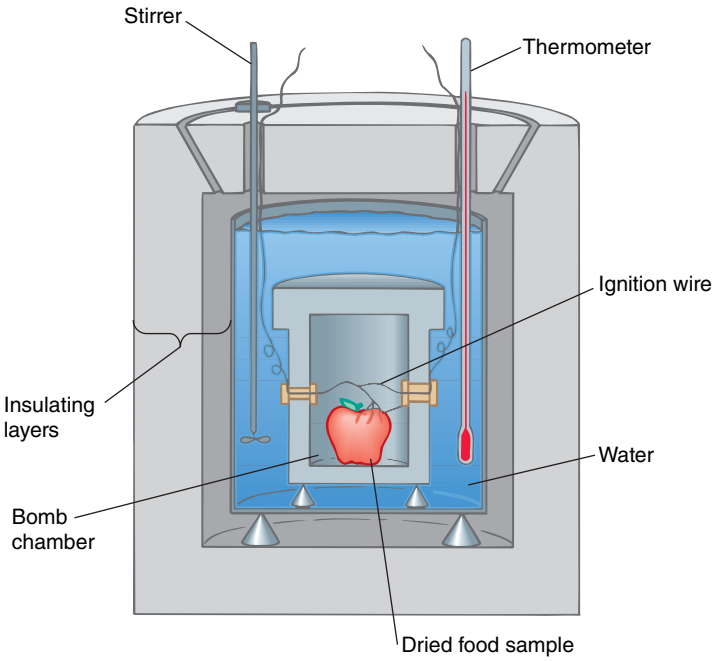


FIGURE 7.10 Bomb calorimeter
When dried food is combusted inside the chamber of a bomb calorimeter, the rise in temperature of the surrounding water can be used to determine the energy content of the food.

© Steve Mcsweeny/iStockphoto

THINK CRITICALLY

This pizza is topped with pepperoni, sausage, and vegetables. How might you modify the pizza in order to reduce the number of calories per slice?

Calculate the energy provided by each macronutrient:
15 g protein × 4 kcal/g = 60 kcal
50 g carbohydrate × 4 kcal/g = 200 kcal
10 g fat × 9 kcal/g = 90 kcal
Calculate the total amount of energy:
Total energy = 60 kcal + 200 kcal + 90 kcal = 350 kcal per slice

FIGURE 7.11 Estimating the energy content of food
Most foods are of mixed composition; for instance, this slice of pizza contains about 15 g of protein, 50 g of carbohydrate, and 10 g of fat. Its energy content can be calculated as shown in the table.

OFF THE LABEL

How Many Calories in That Bowl, Box, or Bottle?

© iStockphoto

Are you watching your calorie intake? The Nutrition Facts portion of a food label can help, if you read it carefully. It provides information about calories per serving and serving size. Make sure you check both.

People tend to eat in units—one bottle of juice, one can of soda, one bag of potato chips—but the serving size on the current Nutrition Facts label doesn't always reflect the calorie count for those units. For example, the current food label (left) says that a serving has only 100 kcal. But, the serving size of iced tea or juice drink is 8 oz, and the bottle holds 20 oz. So if you finish the bottle, you will be getting 250 kcal, mostly from added sugars. The label on the right shows the proposed changes to the food label, which would make the Calories per serving more prominent and increase the serving size to one bottle, the amount people typically consume.

Current food label

Nutrition Facts

Serving Size 8 fl oz (240 mL)
Servings Per Container 2.5

Amount Per Serving

Calories 100

% Daily Value*

Total Fat 0 g **0%**

Proposed food label

Nutrition Facts

1 Serving per container

Serving Size 1 bottle (20 fl oz)

Amount Per 20 fl oz

Calories 250

% DV*

0% **Total Fat 0 g**

David Paul Morris/Getty Images

The discrepancy between the "serving sizes" listed on packages and the "portion sizes" we consume is one of the reasons Americans are getting fatter. We choose portions that are generally larger than recommended. For example, the label on your ice cream shows that it provides about 140 kcal per serving and that a serving is ½ cup, a portion the size of half a tennis ball. If you scoop a cup of ice cream onto your cone or into your bowl, you will be consuming about 280 kcal. Likewise, the serving of granola cereal listed on the label may be as small as a quarter cup. If you pour yourself a cup of granola for breakfast, you are probably consuming over 400 kcal.

By law, the serving sizes on food labels must be based on what people actually eat, not on what they "should" be eating. The serving sizes currently shown on food labels reflect what people ate in the 1990s; proposed label changes will update the serving sizes to reflect today's eating patterns. In addition, proposed changes would require packaged foods that are typically consumed in one sitting (such as the iced tea) to be labeled as a single serving. For packages that are larger, but could be consumed in one sitting, manufacturers would have to provide "dual-column" labels to indicate both "per serving" and "per package" calories and nutrient information. For example, the label on a pint of ice cream would provide both single serving and entire container information.

Knowing how your portion size compares with the serving size on the label can help you keep your calories under control. Measuring can help. If you pour cereal into your bowl or spoon pasta onto your plate and then measure how much you have served yourself, you can judge how many calories you are about to consume.

THINK CRITICALLY: Would the proposed changes to the Nutrition Facts label make you more aware of the number of calories you are consuming?

How the Energy in Food Is Converted into ATP Just as the energy in flowing water can be converted into electrical energy, which can then be converted into the light energy emitted by a light bulb, the energy stored in the chemical bonds of carbohydrates, fats, and proteins can be converted into ATP, which can be used to keep you alive and moving. To generate ATP, the carbohydrates, proteins, and triglycerides consumed in the diet are

TABLE 7.2 Using Choice (Exchange) Lists to Estimate Energy Content

Food groups/lists	Serving size	Energy (kcal)
Carbohydrate group		
Starch	⅓ cup pasta; ½ cup potatoes; 1 slice bread	80
Fruit	1 small apple, peach, pear; ½ banana; ½ cup canned fruit (in juice)	60
Milk	1 cup milk or yogurt	
Nonfat		90
Low-fat		110
Reduced-fat		120
Whole		150
Other carbohydrates	Serving sizes vary	Varies
Vegetables	½ cup cooked vegetables, 1 cup raw	25
Meat/meat substitute group	1 oz meat or cheese; ½ cup legumes	
Very lean		35
Lean		55
Medium-fat		75
High-fat		100
Fat group	1 tsp butter, margarine, or oil; 1 T salad dressing	45

digested and absorbed. The resulting glucose, amino acids, and fatty acids are then broken down, or oxidized, to generate ATP. Each of these nutrients can be converted into the common intermediate acetyl-CoA. Glycolysis converts glucose into pyruvate, which then loses a carbon to form acetyl-CoA. β-Oxidation breaks fatty acids into two-carbon units that form acetyl-CoA, and after deamination the carbon skeletons from amino acid can be used to make acetyl-CoA or other intermediates. Acetyl-CoA can then enter the citric acid cycle. The high-energy electrons released at various steps of cellular respiration are passed to the electron transport chain where their energy is trapped and used to generate ATP (Figure 7.12; also see Chapters 4 through 6 and online Focus on Metabolism). The ATP is then used to fuel metabolic reactions that build and maintain body components and to power other cellular and body activities. Much of the energy consumed in food is also converted to and lost from the body as heat.

Energy Out: Calories Used by the Body

Energy is defined as the ability to do work. In the body, energy is used to do body work. The total amount of energy used by the body each day, or **total energy expenditure (TEE)**, includes the energy needed to maintain basic bodily functions, such as the beating of your heart, and that needed to fuel activity and process food. In individuals who are growing or pregnant, TEE also includes the energy used to deposit new tissues. In women who are lactating, it includes the energy used to produce milk. A small amount of energy is also used to maintain body temperature in a cold environment.

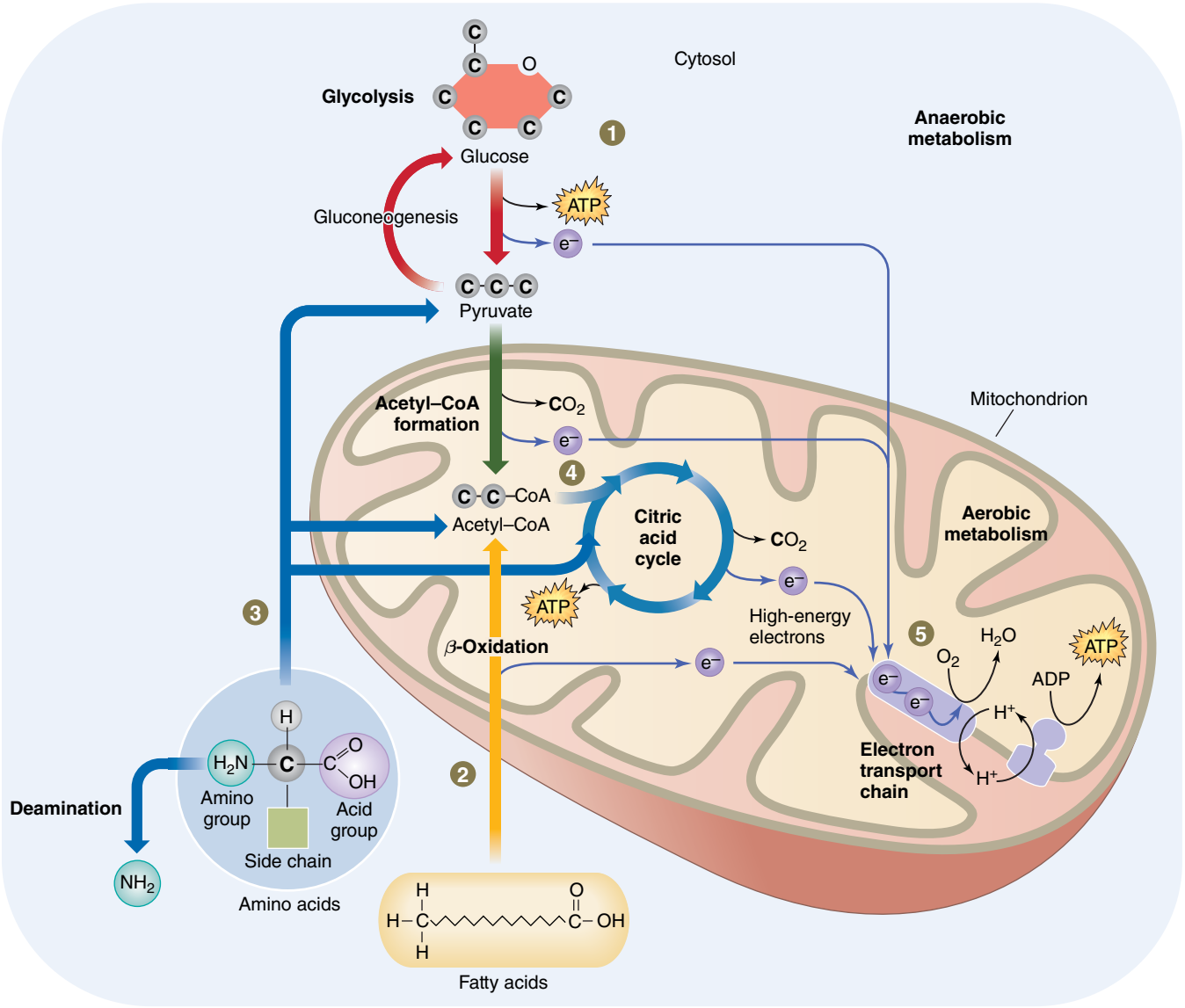
total energy expenditure (TEE) The sum of the energy used for basal metabolism, activity, processing of food, deposition of new tissue, and production of milk.

basal energy expenditure (BEE) The energy expended to maintain an awake resting body that is not digesting food.

basal metabolic rate (BMR) The rate of energy expenditure under resting conditions. BMR measurements are performed in a warm room in the morning before the subject rises and at least 12 hours after the last food or activity.

Energy for Basal Metabolism For most people, about 60 to 75% of the body's total energy expenditure is used for basal metabolism. Basal metabolism, or **basal energy expenditure (BEE)**, includes all the involuntary things your body does to stay alive such as breathing, circulating blood, regulating body temperature, maintaining body tissues, removing waste products, and sending nerve signals. The rate at which energy is used for these basic functions is called the **basal metabolic rate (BMR)** and is often expressed in kilocalories per hour. Basal needs include the energy necessary for essential metabolic reactions and life-sustaining functions but do not include the energy needed for physical activity or for the digestion of food and the absorption of nutrients. Therefore, to minimize residual energy expenditure for activity or processing food, BMR is measured in the morning, in a warm room before the subject rises, and at least 12 hours

FIGURE 7.12 Producing ATP from glucose, fatty acids, and amino acids
Glucose, fatty acids, and amino acids can be broken down by the reactions of cellular respiration to yield carbon dioxide, water, and energy in the form of ATP.



1. Glycolysis breaks glucose in half to yield two pyruvate molecules that are converted to acetyl-CoA.
2. β-Oxidation breaks fatty acids into two-carbon units that form acetyl-CoA.
3. After deamination, amino acids can break down to form acetyl-CoA, pyruvate, or other intermediates.
4. The acetyl-CoA from glucose, fatty acid, and amino acid breakdown can enter the citric acid cycle.
5. The electrons released are passed to the electron transport chain, and their energy is used to convert ADP to ATP.

resting energy expenditure (REE) or **resting metabolic rate (RMR)** Terms used when an estimate of basal metabolism is determined by measuring energy utilization after five to six hours without food or activity.

after food intake or activity (Figure 7.13). Because of the difficulty of achieving these conditions, measures are often made after about five to six hours without food or activity. When done under these conditions, the measurement is reported as **resting energy expenditure (REE)** or **resting metabolic rate (RMR)**. RMR values are about 10 to 20% higher than BMR values.[30]

Basal needs are affected by factors such as body weight, gender, growth rate, age, and even diet. BMR increases with increasing body weight, so it is higher in heavier individuals. It also rises with increasing lean body mass; thus, BMR is generally higher in men than in women because men have more lean tissue. BMR increases during periods of rapid growth because energy is required to

produce new body tissue. It decreases with age, partly due to the decrease in lean body mass that usually occurs in older adults. BMR is decreased by low-energy diets and weight loss.[31,32] This is a beneficial adaptation in starvation, but it makes weight loss and maintenance of weight loss more difficult.

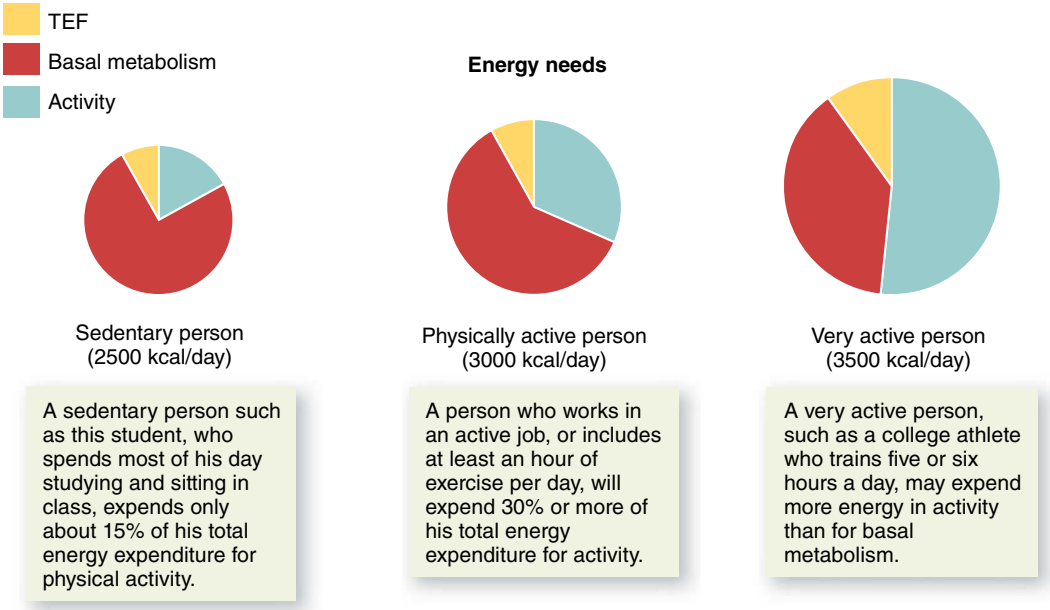
Basal needs can be altered by certain abnormal conditions. An elevation in body temperature increases BMR. It is estimated that BMR increases by 7% for every 1 degree Fahrenheit above normal body temperature. This extra energy use explains why a fever can cause weight loss. Abnormal levels of thyroid hormones can also affect BMR. Individuals who overproduce these hormones burn more energy; in fact, a symptom used to diagnose thyroid hormone excess is unexplained weight loss. Individuals with an underproduction of thyroid hormones require less energy. The fact that hormones produced by the thyroid gland affect energy expenditure is the reason that obesity was once explained as a glandular problem. It is now known that obesity due to a thyroid hormone deficiency is rare.

Physical Activity Physical activity is the second major component of energy expenditure. It represents the metabolic cost of external work, which includes both the energy needed for planned exercise and that needed for daily activities such as walking to work, typing, performing yard work, house cleaning, and even fidgeting. The energy expended for daily activities is called **nonexercise activity thermogenesis (NEAT)** and includes the energy expended for everything that does not involve sleeping, eating, or sports-like exercise. NEAT accounts for the majority of the energy expended for activity, and it varies enormously depending on an individual's occupation and daily movements. For most people, physical activity accounts for 15 to 30% of energy requirements, but this varies greatly (Figure 7.14).

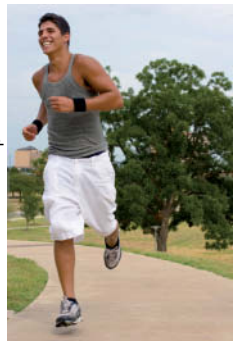
St Bartholomews Hospital/Science Source Images

FIGURE 7.13 Measuring BMR
To assess BMR, expired gases can be collected and measured by having the subject breathe into a hood. Because aerobic metabolism uses oxygen and produces carbon dioxide, the amounts of these gases in expired air can be used to estimate the amount of energy that is being used.

nonexercise activity thermogenesis (NEAT)
The energy expended for everything we do other than sleeping, eating, or sports-like exercise.



© zhang bo/iStockphoto



© hammondovi/iStockphoto

Image Source/Getty Images, Inc.

FIGURE 7.14 Activity as a portion of total energy requirement
These pie charts show the approximate energy expenditure for a 19-year-old male in various activity categories. More active individuals have greater TEE and expend a greater proportion of their energy for activity.

The energy required for an activity depends on how strenuous the activity is and the length of time it is performed. For example, walking at a speed of 3 to 4 miles per hour requires a moderate degree of exertion and uses about 300 kcal/hr for a 70-kg man. The energy required increases progressively as the walking speed and length of time of the activity continue to increase and as the body weight of the exerciser rises. In addition to the energy expended during exercise, there is a small increase in energy expenditure for a period of time after exercise has been completed. The energy expended for activity is the one component of our total energy needs over which we have control. To maintain health, people today need to consciously increase their physical activity. This does not mean they have to run marathons. Choosing to take the stairs rather than the elevator, walking rather than taking the bus, and riding a bike rather than driving to the store all increase activity. The energy costs of specific activities are listed in Appendix D.

Thermic Effect of Food Our energy comes from food, but we also need energy to digest food and to absorb, metabolize, and store the nutrients from this food. The energy used for these processes is called the **thermic effect of food (TEF)** or **diet-induced thermogenesis**. This energy expenditure causes body temperature to rise slightly for several hours after eating. The energy required for TEF is estimated to be about 10% of energy intake but can vary depending on the amounts and types of nutrients consumed. Because it takes energy to store nutrients, TEF increases with the size of the meal. A meal that is high in fat has a lower TEF than a meal high in protein or carbohydrate because dietary fat can be used or stored more efficiently than either protein or carbohydrate. The metabolic cost of either oxidizing or storing dietary fat is only 2 to 3% of the energy consumed, whereas the cost of using amino acids by either oxidizing them or incorporating them into proteins is 15 to 30% of the energy consumed, and the cost of breaking down carbohydrate or storing it as glycogen is 6 to 8%.[33] The difference in the cost of storing different nutrients as fat means that a diet high in fat may produce more body fat than a diet high in carbohydrate.[34]

thermic effect of food (TEF) or **diet-induced thermogenesis** The energy required for the digestion of food and the absorption, metabolism, and storage of nutrients. It is equal to approximately 10% of daily energy intake.

Storing Energy and Using Energy Stores

To function normally, the body needs a steady supply of energy. This energy is provided by our food and our body stores. People typically eat three to six times during the day. When we eat, some nutrients are used for energy and some are stored. Between meals, stored energy is used to meet needs. Typically, these stores are then refilled using energy consumed in the next meal so that there is no net change in the amount of stored energy. However, when we eat in excess, more energy is stored as fat than is needed to supply energy for the day and we gain weight. When our intake is too low, we use our fat stores to meet our daily needs and lose weight (Figure 7.15).

How Feasting Results in Weight Gain When excess energy is consumed (feasting), we generally say this excess is stored as fat. This is an oversimplification of a complex situation. After

FIGURE 7.15 Feasting and fasting When you consume more energy than your body needs at a particular time, the extra energy will be stored as glycogen in your liver and muscle and as fat in your adipose tissue. When you haven't eaten in a while, your body retrieves energy from these stores. During fasting, body protein is also broken down to amino acids to make glucose and provide energy.

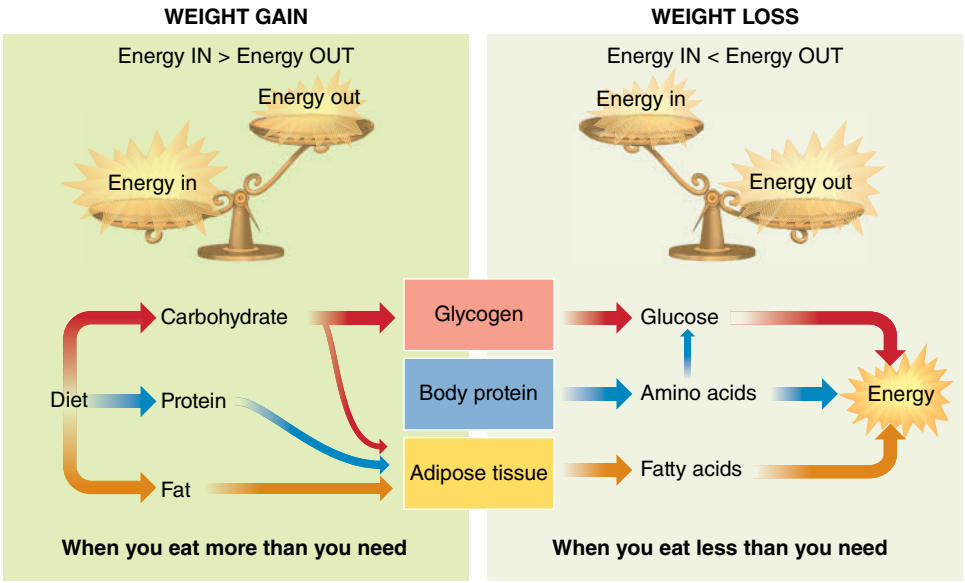


TABLE 7.3 Sources of Energy in the Body[35,36]

Energy source	Primary location	Energy (kcal)[a]
Glycogen	Liver and muscle	1,400
Glucose or lipid	Body fluids	100
Triglyceride	Adipose tissue	140,000
Protein	Muscle	25,000

[a]Values represent the approximate amounts in a 70-kg male.

eating, the body prioritizes how nutrients are used based on body needs, which nutrients can be stored, and how efficiently they can be stored.

Energy is stored in the body as glycogen and triglycerides. Glycogen stores are located in the liver and muscle (Table 7.3). These stores fill up when dietary carbohydrate is adequate. The body generally stores only about 200 to 500 g of glycogen—enough to provide glucose for about 24 hours. Triglycerides are stored in adipose tissue, which is made up of adipocytes. Adipocytes grow in size as they accumulate more triglycerides and shrink as triglycerides are removed from them. The greater the number of adipocytes an individual has, the greater the ability to store fat. Although most adipocytes are formed between infancy and adolescence, excessive weight gain can cause the production of new adipocytes in adults.

Why Most Body Fat Comes from Dietary Fat There is a metabolic hierarchy that determines how fuels are used by the body. Alcohol, although not a nutrient, does supply energy. Because it is toxic and cannot be stored in the body, it is rapidly oxidized. Amino acids from dietary protein are next in the hierarchy. They are first used to synthesize needed body proteins and nitrogen-containing nonprotein molecules; any excess is then broken down to provide energy because there is no mechanism for storing them as amino acids or proteins. Carbohydrate is used to maintain blood glucose and to build glycogen stores. Once glycogen stores are full, the remaining carbohydrate is oxidized for energy. Fat, unlike the other energy- yielding nutrients, is not needed as a fuel for a particular tissue or to build tissues and can be stored in the body in virtually unlimited amounts. Therefore, if the energy consumed is in excess of immediate needs, dietary fat is preferentially stored. For example, after a meal the body's energy needs are met by first breaking down dietary protein and carbohydrate that are not needed for essential functions. To meet any remaining energy needs, dietary fat is oxidized, and any dietary fat that is left is stored as triglycerides, primarily in adipose tissue (Figure 7.16). Therefore, most of the fat that is stored in the body comes directly from dietary fat.

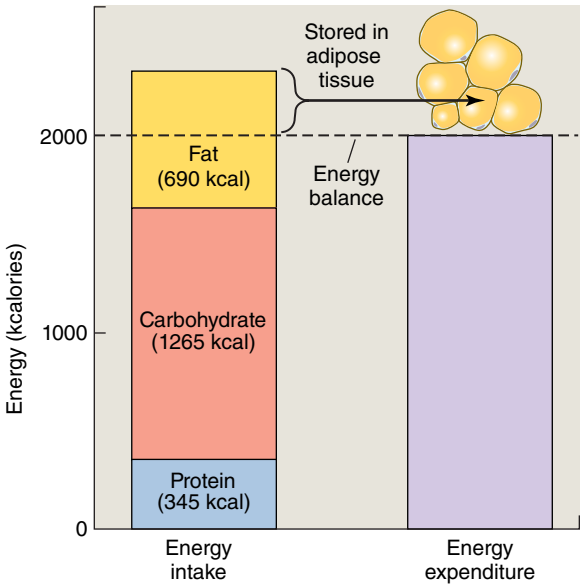


FIGURE 7.16 How dietary energy-yielding nutrients are used
When energy intake exceeds expenditure, dietary fat is stored in adipose tissue. In this example, in which 2000 kcal are needed for energy balance, all the calories from carbohydrate and protein are used to meet the body's need for synthesis and energy, but only some of the calories from fat are used to meet energy needs. The remaining fat calories are stored in adipose tissue.

How Carbohydrate and Protein Can Be Used to Synthesize Fat The body is capable of converting glucose and amino acids into triglycerides for storage, but these conversions are energetically costly (Figure 7.17). Making fat from glucose involves converting glucose to acetyl-CoA and then assembling fatty acids from the two-carbon acetyl-CoA units. The fatty acids must then be joined to a molecule of glycerol to make triglycerides for storage. To convert amino acids to fat, the amino group must first be removed and then the carbon skeleton must be broken down to yield acetyl-CoA that can be used for fatty acid synthesis. In contrast, the conversion of dietary fat to body fat requires only the removal and reattachment of fatty acids from the glycerol backbone (see Chapter 5); it takes only a small percentage of the energy in the fat to store the fat in adipose tissue (see Figure 7.17). The low metabolic cost of converting dietary fat to stored body fat makes it more efficient for the body to use dietary fat to make body fat and to oxidize carbohydrate and protein to meet immediate energy needs rather than convert them to fat. Regardless of the composition of the diet, however, when excess energy is consumed over the long term, fat stores will enlarge and weight will increase.

How Fasting Results in Weight Loss The body needs a steady supply of energy even when we don't eat. Some of this energy must

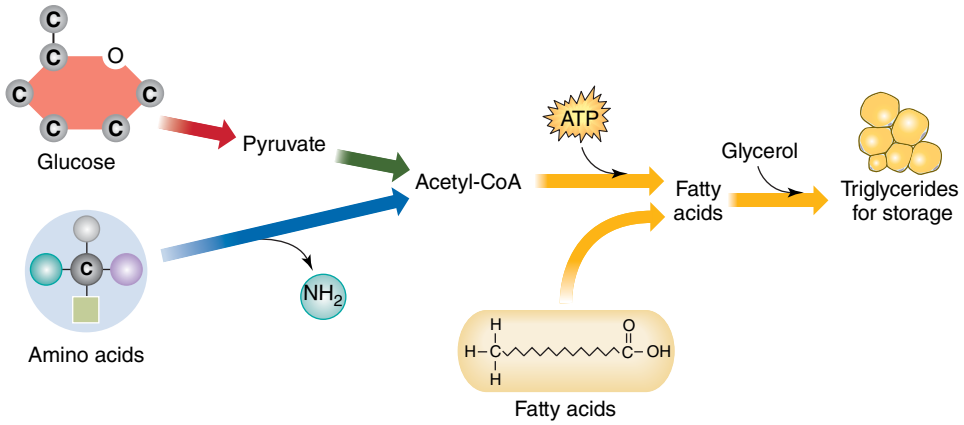


FIGURE 7.17 Storing energy as fat
It is metabolically much simpler and less costly to convert dietary fatty acids to triglycerides for storage than to convert glucose or amino acids to triglycerides.

come from glucose, which is needed to fuel the brain and several other types of body cells. Between meals, the breakdown of glycogen provides glucose and the breakdown of stored fat meets other energy needs. If these energy stores are not fully replenished, the amount of stored energy—and hence, body weight—will decrease (see Figure 7.15).

If no food is eaten for several hours, the body must shift the way it uses energy to ensure that glucose continues to be available to the brain and other cells that need it. Glycogen stores can provide glucose but are limited, so glucose is also supplied by the breakdown of small amounts of body protein, primarily muscle protein, to yield amino acids. Amino acids can then be used to synthesize glucose via gluconeogenesis (see Chapters 4 and 6). Once glycogen stores are depleted, all of the glucose must come from gluconeogenesis. Because protein is not stored in the body, the breakdown of protein to provide energy and glucose results in the loss of functional body proteins.

Energy for tissues that don't require glucose is provided by the breakdown of stored fat. If the supply of glucose is limited, such as during fasting, fatty acids delivered to the liver cannot be completely oxidized, so ketones are produced (see Chapter 4). Ketones can be used as an energy source by many tissues. After about three days of fasting, even the brain adapts to meet some of its energy needs from ketones (see Chapter 5 and online Focus on Metabolism). This reduces the amount of glucose needed and thus slows the rate of protein breakdown.

If energy intake is less than energy output for a prolonged period, substantial amounts of fat are used to provide energy and some protein is degraded to provide glucose. This results in weight loss (see Figure 7.15). The magnitude of the weight loss depends on the degree of energy deficit and the length of time over which it occurs. It is estimated that an energy deficit of about 3500 kcal will result in the loss of a pound of adipose tissue.

7.4 Estimating Energy Requirements

LEARNING OBJECTIVES

- Describe three ways in which energy expenditure is measured.
- Tally your daily physical activity and determine your PA value.
- Calculate your EER using your PA value and the appropriate EER equation.

Estimated Energy Requirements (EERs) The amount of energy recommended by the DRIs to maintain body weight in a healthy person based on age, gender, size, and activity level.

The amount of energy expended by the body, and hence the energy needed to maintain body weight, can be measured using a variety of techniques. Data from these measurements can then be used to estimate energy needs for a variety of people under a variety of circumstances. Calculations of energy expenditure have been used to generate the **Estimated Energy Requirements (EERs)** (see Chapter 2), which are the current recommendations for energy intake in the United States. An EER is the number of calories needed for a healthy individual to maintain his or her weight.

How Energy Expenditure Is Measured

Energy expenditure can be measured by calorimetry, which is the science of measuring heat flow. Calorimetry can determine energy expenditure directly or indirectly. Measuring doubly labeled water is another technique for assessing energy expenditure; this method can be used over prolonged periods.

Direct Calorimetry Measuring the amount of heat produced when a food is combusted in a bomb calorimeter is a type of **direct calorimetry** (see Figure 7.10). In humans, direct calorimetry measures the amount of heat given off by the body; the heat produced is proportional to the amount of energy used. This heat is generated by metabolic reactions that both convert food energy into ATP and use ATP to power body processes. Direct calorimetry is an accurate method for measuring energy expenditure, but it is expensive and impractical because it requires that the individual being assessed remain in an insulated chamber throughout the procedure in order to measure the heat produced.

direct calorimetry A method of determining energy use that measures the amount of heat produced.

Indirect Calorimetry **Indirect calorimetry**, which estimates energy use by assessing oxygen utilization, is somewhat less cumbersome than direct calorimetry. To obtain a measurement, the researcher has the subject breathe into a mouthpiece, mask, or ventilated hood (**Figure 7.18**). Oxygen use and carbon dioxide production are measured by analyzing the difference between the composition of inhaled and exhaled air. The body's energy use can be calculated from these values because the burning of fuels by the body in cellular respiration uses oxygen and produces carbon dioxide. This method can measure the energy used for individual components of expenditure, such as physical activity or BMR. It can also be used to estimate total energy needs, but it is not practical in free-living individuals because the equipment is too cumbersome for long-term use.

indirect calorimetry A method of estimating energy use that compares the amount of oxygen consumed to the amount of carbon dioxide expired.

Doubly Labeled Water A more practical method for measuring energy needs over long periods is the **doubly labeled water technique**. This involves having the subject ingest or be injected with water labeled with **isotopes** of oxygen and hydrogen. The labeled oxygen and hydrogen are used by the body in metabolism. The labeled hydrogen leaves the body as part of water molecules and the labeled oxygen leaves the body as part of both water and carbon dioxide molecules. The difference in the rates of disappearance of these two isotopes can be used to calculate the amount of carbon dioxide produced by metabolic reactions in the body.

The doubly labeled water technique does not require the individual to carry any equipment and can be used to measure energy expenditure in free-living subjects for periods of up to two weeks. It is now the preferred method for determining the total daily energy expenditures of both healthy and clinical populations.[30] However, it is not helpful in determining the proportion of energy used for BMR, physical activity, or TEF.

doubly labeled water technique A method for measuring energy expenditure based on measuring the disappearance of isotopes of hydrogen and oxygen in body fluids after consumption of a defined amount of water labeled with both isotopes.

isotopes Alternative forms of an element that have different atomic masses and may or may not be radioactive.

Stockbyte/Getty Images, Inc.

FIGURE 7.18 Collecting expired gases to measure energy use
Indirect calorimetry can be used to assess the energy expended for specific activities. Subjects breathe into a mouthpiece or through a mask that is placed over their nose and mouth. The amounts of O_2 and CO_2 in the inhaled and exhaled air are measured.

How to Calculate EER

Measurements of energy expenditure using doubly labeled water have been used to develop equations for estimating individuals' energy needs. These EER equations are used to estimate the amount of energy needed to maintain energy balance in a healthy person of a given age, gender, weight, height, and level of physical activity.[30] No specific RDAs or ULs for energy have been established.

Determine Physical Activity Level To calculate an individual's energy needs using the EER equations, his or her physical activity level must be estimated. This can be done by keeping a daily log of activities and the amount of time spent at each. Physical activity level can then be categorized as sedentary, low active, active, or very active.

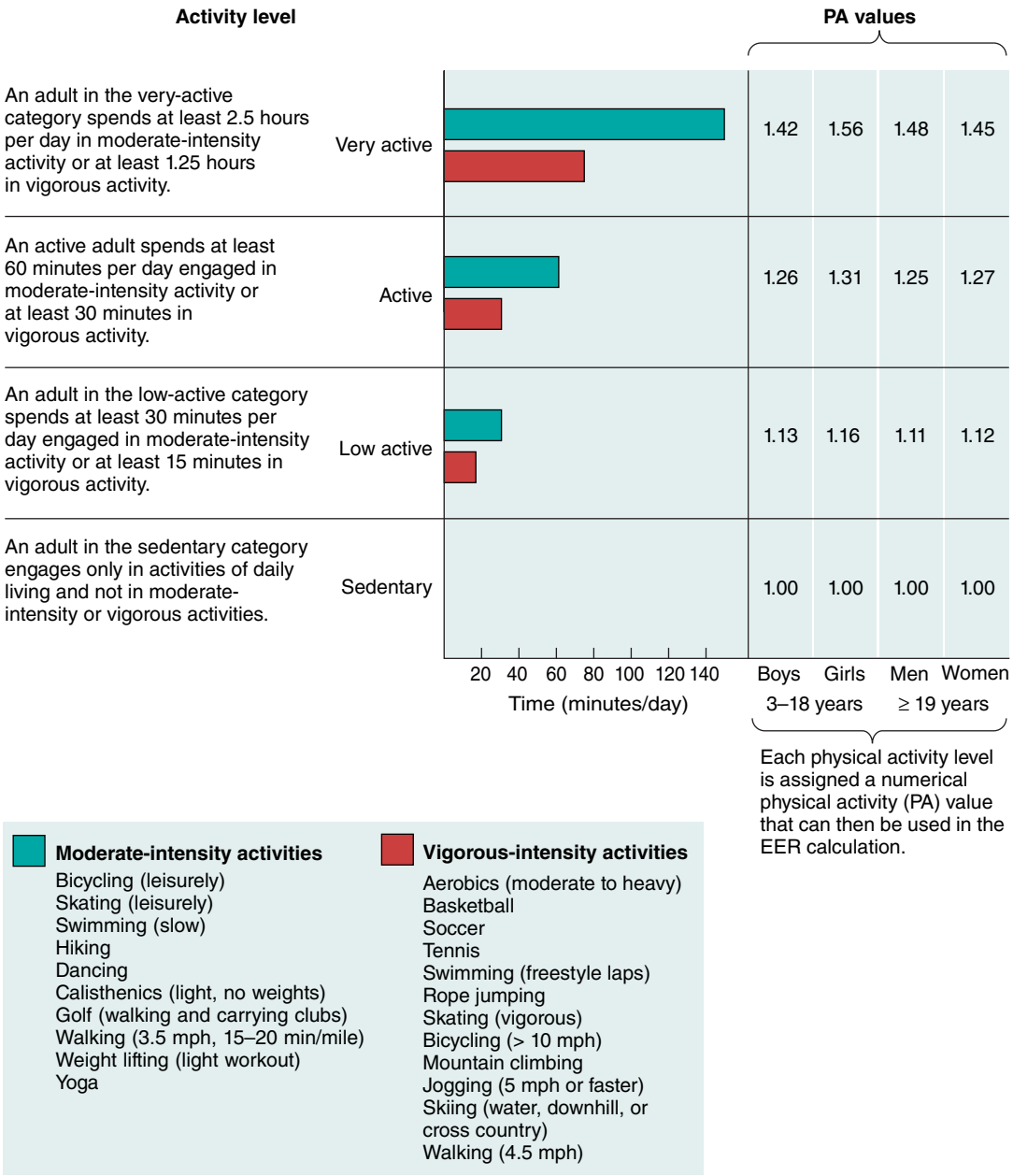


FIGURE 7.19 Physical activity level and PA values
Physical activity level, which is used to calculate EER, is categorized as sedentary, low active, active, or very active. A sedentary person spends about 2.5 hours per day engaged in the activities of daily living, such as housework, homework, and yard work. Adding activity moves the person into the low-active, active, or very-active category. Activity can be moderate or vigorous or a combination of the two; compared to moderate-intensity activity, vigorous activity will burn more calories in the same amount of time.

PA (physical activity) value
A numerical value associated with activity level that is a variable in the EER equations used to calculate energy needs.

Figure 7.19 can be used to translate the amount of time spent engaged in moderate-intensity or vigorous activities into one of these four physical activity levels. Each activity level corresponds to a numerical **PA (physical activity) value** that can be used in the EER equations. For example, if you spend about an hour a day walking (a moderate-intensity activity) or about 30 minutes jogging (a vigorous activity), you are in the active category and should use the active PA value corresponding to your age and gender when calculating your EER.

Activity level has a significant effect on energy needs. For example, a 30-year-old woman who is 5′5″ tall and weighs 130 lb needs about 1900 kcal/day if she is at the sedentary activity level. If she increases her activity to "active," the level recommended by the DRIs, her energy needs increase to 2370 kcal/day.

Choose the Appropriate EER Equation Energy needs are affected by gender, height, weight, life stage, and age as well as level of physical activity. These factors are all taken into

TABLE 7.4 Calculating Your EER

• Find your weight in kilograms (kg) and your height in meters (m):

Weight in kilograms = weight in pounds ÷ 2.2 lb/kg

Height in meters = height in inches × 0.0254 m/in.

For example: 160 pounds = 160 lb ÷ 2.2 lb/kg = 72.7 kg

5′9″ = 69 in. × 0.0254 m/in. = 1.75 m

• Estimate the amount of physical activity you get per day and use Figure 7.19 to find the PA value for someone your age, gender, and activity level:

For example, if you are a 19-year-old male who performs 40 minutes of vigorous activity a day, you are in the active category and have a PA value of 1.25.

• Choose the appropriate EER prediction equation below, and calculate your EER:

For example, if you are an active 19-year-old male:

EER = 662 − (9.53 × age in yr) + PA [(15.91 × weight in kg) + (539.6 × height in m)]

where age = 19 yr, weight = 72.7 kg, height = 1.75 m, active PA value = 1.25.

EER = 662 − (9.53 × 19) + 1.25 ([15.91 × 72.7] + [539.6 × 1.75]) = 3107 kcal/day

Life stage	EER prediction equation[a]
Boys 9–18 yr	EER = 88.5 − (61.9 × age in yr) + PA[(26.7 × weight in kg) + (903 × height in m)] + 25
Girls 9–18 yr	EER = 135.3 − (30.8 × age in yr) + PA[(10.0 × weight in kg) + (934 × height in m)] + 25
Men ≥ 19 yr	EER = 662 – (9.53 × age in yr) + PA[(15.91 × weight in kg) + (539.6 × height in m)]
Women ≥ 19 yr	EER = 354 − (6.91 × age in yr) + PA[(9.36 × weight in kg) + (726 × height in m)]

[a]These equations are appropriate for determining energy expenditure in normal-weight individuals.

consideration in the EER equations (Table 7.4 or inside cover). Separate equations for men and women reflect gender differences in energy requirements. As age increases in adults, energy needs decrease. Height and weight are variables in the equations, and when larger numbers are entered, calculated results reflect the higher energy needs of taller, heavier individuals. The impact of changing some of these variables is illustrated in Figure 7.20. EERs predict energy expenditure in normal-weight individuals. Equations that predict the amount of energy needed for weight maintenance for individuals who are overweight or obese are given in Appendix A.

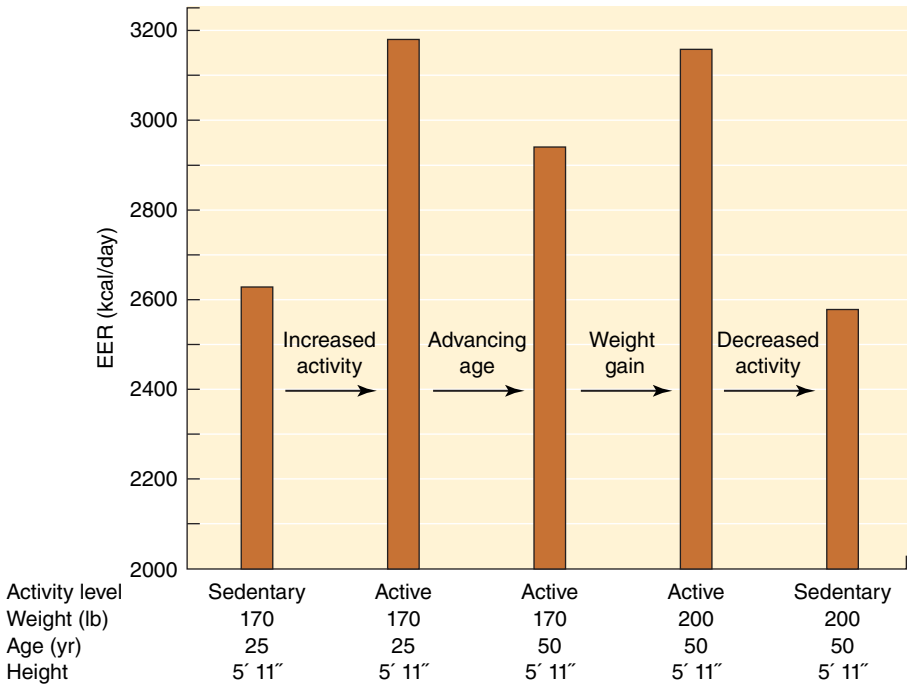


FIGURE 7.20 Variables that affect energy requirements
A sedentary 25-year-old man who is 5′11″ tall and weighs 170 lb requires 2624 kcal to maintain his weight. If he begins exercising an hour a day, he will need to eat 3174 kcal to prevent weight loss. As this man ages, his EER declines. If he gains weight, his energy needs will increase. If he decreases his level of activity, the number of calories he can eat without gaining weight will drop.

The EER values for infants, children, and adolescents include the energy used to deposit tissues associated with growth. Beginning at age 3, different EER equations are used for boys and girls because of differences in growth and physical activity (see inside cover). The EER for pregnancy is determined as the sum of the total energy expenditure of a nonpregnant woman plus the energy needed to maintain pregnancy and deposit maternal and fetal tissue. During lactation, EER is the sum of the total energy expenditure of nonlactating women and the energy in the milk produced, minus the energy mobilized from maternal tissue stores.

7.5 What Determines Body Size and Shape?

LEARNING OBJECTIVES

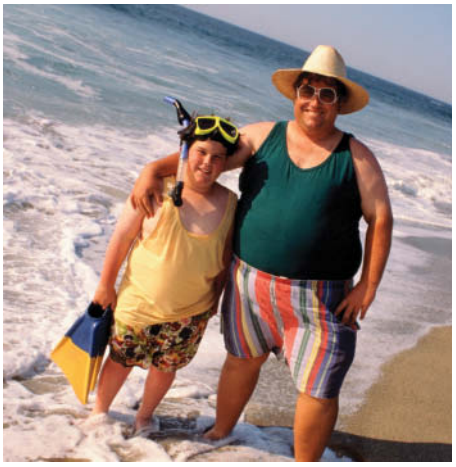
- Discuss genetic and environmental factors that affect body weight.
- Describe what is meant by a set point for body weight.
- List four physiological signals that determine whether you feel hungry or full.
- Explain why leptin levels might be higher in an individual who is obese than in a lean individual.

obesity genes Genes that code for proteins involved in the regulation of food intake, energy expenditure, or the deposition of body fat. When they are abnormal, the result is abnormal amounts of body fat.

Most people are shaped like their mother or father. This is because the information that determines body size and shape is contained in the genes people inherit from their parents. Some of us inherit long, lean bodies, and others inherit huskier builds and the tendency to put on pounds (Figure 7.21). Genes involved in regulating body fatness have been called **obesity genes**. Obesity genes are responsible for the production of proteins that affect how much food people eat, how much energy they expend, and how efficiently their body fat is stored. The combined effects of all these genes help to determine and regulate what people weigh and how much fat they carry. But genes are not the only factor; regardless of your genetic background, the lifestyle choices you make play an important role in determining what you weigh. The drastic rise in obesity that has occurred during the past several decades demonstrates the impact of lifestyle factors on weight. The frequency of genes in a population takes many generations to change, but environmental conditions that affect lifestyle can change quickly.

Genes versus Environment

The genes you inherit are an important determinant of what you weigh. If one or both of your parents are obese, your risk of becoming obese is increased. Individuals with a family history



Bruce Ayres/Stone/Getty Images, Inc.

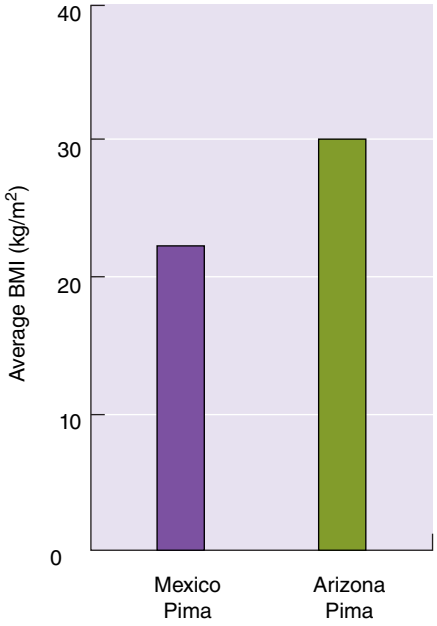
Courtesy Lori Smolin

FIGURE 7.21 Genes and body shape
The genes we inherit from our parents are important determinants of our body size and shape. The boy on the right inherited his father's long, lean body, whereas the boy on the left has his father's huskier build and will likely have a tendency to be overweight throughout his life.

FIGURE 7.22 Genes vs. lifestyle of the Pima Indians

A. Genetic analysis of the Pima Indian population living in Arizona has identified a number of genes that may be responsible for this group's tendency to store excess body fat.[41] When this genetic susceptibility is combined with an environment that fosters a sedentary lifestyle and consumption of high-calorie, high-fat processed foods, the outcome is the strikingly high incidence of obesity seen in this population.

Matt York/AP/Wide World Photos



B. The Pima Indians of Mexico have the same genetic susceptibility to obesity as the Arizona Pimas but are farmers who work in the fields and consume the food they grow.[42] They still have higher rates of obesity than would be predicted from their diet and exercise patterns, but their average BMI is significantly lower than that of the Arizona Pimas.[40]

of obesity are two to three times more likely to be obese, and the risk increases with the magnitude of the obesity.[37] The influence of genes on body weight was demonstrated dramatically by a classic study done with identical twins. During the study, the pairs of identical twins were overfed to the same extent. Each set of twins tended to gain the same amount of weight and to deposit fat in the same parts of their bodies. In contrast, large differences were seen between sets of twins—some of the twin sets gained only 9 lb, whereas others gained as much as 29 lb.[38] By studying twins, researchers have been able to determine that about 40 to 70% of the variation in BMI between individuals can be attributed to genes.[39] This means that the remaining 30 to 60% is determined by the environment in which you live and the lifestyle choices you make. So even if you inherit genes that predispose you to being overweight, your actual weight is determined by the balance between the genes you inherit and your lifestyle choices.

When genetically susceptible individuals find themselves in an environment where food is appealing and plentiful and physical activity is easily avoided, obesity is a likely outcome but not the only possible one. If people who inherit genes that predispose them to being overweight carefully plan their food intake and exercise regularly, they can maintain a healthy weight. It is also possible for individuals with no genetic tendency toward obesity to end up overweight if they consume a high-calorie diet and get little exercise. The interplay between genetics and lifestyle is illustrated by the higher incidence of obesity in Pima Indians living in Arizona than in a genetically similar group of Pima Indians living in Mexico (Figure 7.22).[40]

How Food Intake and Body Weight Are Regulated

What we eat and how much activity we get vary from day to day, but body weight tends to remain relatively constant for long periods. The body compensates for variations in diet and activity by adjusting energy intake and expenditure to keep weight at a particular level, or **set point**. This set point, which is believed to be determined in part by genes, explains why your

set point A level at which body fat or body weight seems to resist change despite changes in energy intake or output.

weight remains fairly constant, despite the added activity of a weekend hiking trip, or why most people gain back the weight they lose when they follow a weight-loss diet.

To regulate weight and fatness at a constant level, the body must be able to respond both to changes in food intake that occur over a short time frame and to changes in the amount of stored body fat that occur in the long term. Signals related to food intake affect hunger and **satiety** over a short period of time—from meal to meal—whereas signals from the adipose tissue trigger the brain to adjust both food intake and energy expenditure for long-term regulation. Information from short-term and long-term signals is integrated by the central nervous system in order to modulate food intake and energy expenditure. The combination of and response to all this information determine energy stores.[43]

satiety The feeling of fullness and satisfaction, caused by food consumption, that eliminates the desire to eat.

Short Term: How Food Intake Is Regulated from Meal to Meal How do you know how much to eat for breakfast or when it is time to eat lunch? Some of the stimulus to eat or not eat is due to external factors such as the appeal of the food or social circumstances, and some is due to emotions; some people may lose their appetite when stressed and others may eat more. However, most of the signals that tell us we are hungry or satiated are physiological. These signals come from the GI tract, levels of circulating nutrients, and the brain.[44] Some signals are sent before food is eaten, some are sent while food is in the GI tract, and some occur once nutrients are circulating in the bloodstream.

The simplest type of signal about how much food has been eaten comes from local nerves in the walls of the stomach and small intestine that sense the volume or pressure of food and send a message to the brain to either start or stop eating. The presence of nutrients in the GI tract also triggers the release of gastrointestinal peptide hormones that interact with the nervous system to affect hunger or satiety. Once nutrients have been absorbed, circulating levels of nutrients, including glucose, ketones, and fatty acids, are monitored by the brain and may trigger signals to eat or not to eat.[44]

ghrelin A peptide hormone produced by the stomach that stimulates food intake.

A number of gastrointestinal hormones help regulate food intake. The hormone **ghrelin** is the only gut hormone that increases appetite.[44] It has been referred to as the "hunger hormone" and may be the reason people typically feel hungry around lunchtime regardless of when and how much they had for breakfast. It is produced by the stomach and is believed to stimulate the desire to eat meals at usual times. Blood levels of ghrelin rise an hour or two before a meal and drop very low after a meal. Levels have been found to rise in people who have lost weight, increasing their desire to eat more.[45] Several gastrointestinal hormones suppress appetite. Cholecystokinin is released by the small intestine when chyme enters. It slows stomach emptying and sends a signal to the brain, both of which contribute to feelings of satiety, causing us to stop eating.[44] Peptide YY is released from the GI tract after a meal. The amount released is proportional to the number of calories in the meal and levels remain elevated for several hours. Studies show that administration of peptide YY reduces food intake and obese patients have been found to have lower levels of this hormone following a meal than normal-weight subjects.[46]

Long Term: How the Amount of Body Fat Is Regulated Short-term regulators of energy balance affect the size and timing of individual meals, but if a change in food intake is sustained over a long period, it can affect long-term energy balance and, hence, body weight and fatness. To regulate the amount of fat at a set level, the body must be able to monitor how much fat is present. This information is believed to come from hormones, such as insulin and **leptin**, which are secreted in proportion to the amount of body fat.[44] Insulin is secreted from the pancreas when blood glucose levels rise; its circulating concentration is proportional to the amount of body fat. Insulin interacts with a portion of the brain called the hypothalamus to reduce food intake and body weight, and insulin levels are believed to affect the amount of leptin produced and secreted. Leptin is produced by adipocytes and acts in the hypothalamus. The amount of leptin produced is proportional to the size of adipocytes—more leptin is released as fat stores increase. Leptin exerts its effect on food intake and energy expenditure by binding to leptin receptors present in the hypothalamus. This triggers mechanisms that affect energy intake and expenditure. When leptin levels are high, mechanisms that increase energy expenditure and decrease food intake are stimulated, and pathways that promote food intake and hence weight gain are inhibited. When fat stores shrink, less leptin is released. Low leptin levels in the brain allow pathways that decrease energy expenditure and increase food intake to become active.[44] Unfortunately, leptin regulation, like other regulatory mechanisms, is much better at preventing weight loss than at

leptin A peptide hormone produced by adipocytes that signals information about the amount of body fat.

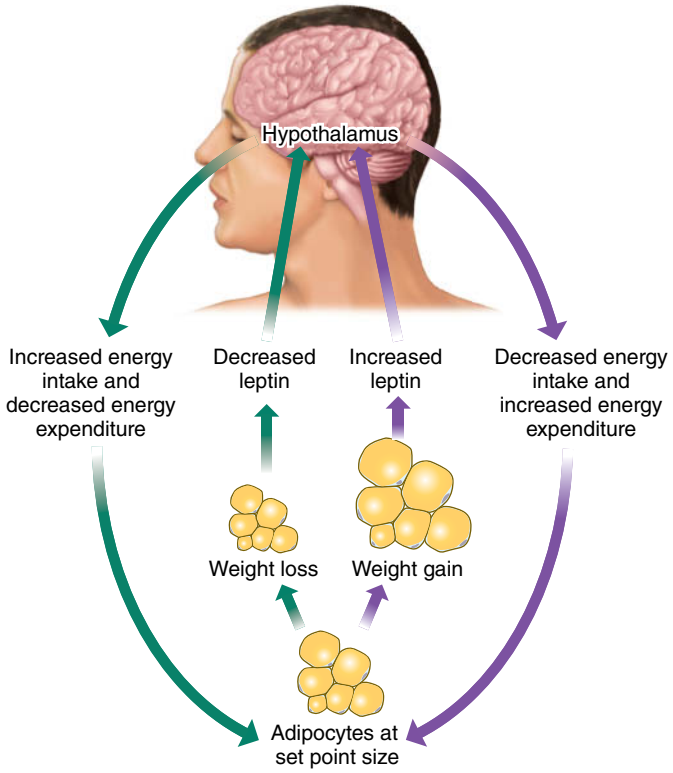


FIGURE 7.23 Leptin regulation of body fat Changes in the size of the adipocytes affect the amount of leptin released. The amount of leptin reaching the hypothalamus determines the response and helps return body fat stores to a set level.

THINK CRITICALLY

What might happen to body weight in a person who makes leptin normally but whose leptin receptor in the brain is defective so it always acts as if large amounts of leptin are bound to it? To a person who makes more leptin than normal?

defending against weight gain. Individuals who are obese generally have high levels of leptin, but these levels are not effective at reducing calorie intake and increasing energy expenditure (Figure 7.23; see **Science Applied: Leptin: Discovery of an Obesity Gene**).[47]

Despite regulatory mechanisms that act to keep our weight at a stable set point, changes in physiological, psychological, and environmental circumstances cause the level at which body weight is maintained to change, usually increasing it over time. For example, body weight increases in most adults between the ages of 30 and 60 years, and after childbearing, most women return to a weight that is 1 to 2 lb higher than their prepregnancy weight. This supports the hypothesis that the mechanisms that defend against weight loss are stronger than those that prevent weight gain.[43]

Why Some People Gain Weight Easily

When a gene is defective, the protein it codes for is not made or is made incorrectly. When an obesity gene, such as the gene for leptin, is defective, the signals to decrease food intake and/or increase energy expenditure are not received, and weight gain results. Scientists have identified a few rare individual gene mutations that cause obesity, including defects in the genes for leptin and leptin receptors.[39,48] However, the majority of obesity is caused by the interaction of many genes that affect metabolic rate, food intake, fat storage, and activity level. These in turn affect body weight, determining why some of us stay lean and others put on pounds easily.

Some People Have a "Thrifty" Metabolism Throughout human history, starvation has threatened survival. Over time, the human body has evolved ways to conserve body fat stores and prevent weight loss. Individuals who are more efficient at using energy and storing fat, what has been called a "thrifty" metabolism, would have been more likely to survive. In the United States today, however, food is abundant, so people who inherit genes that make them efficient at using and storing energy, such as the Pima Indians discussed earlier, gain weight more easily and are more likely to be obese.

How much weight an individual gains in response to overeating also depends on the ability of his or her metabolism to respond to the increase in energy intake relative to expenditure. Occasional overeating causes metabolism to speed up to burn the extra energy and prevent weight gain.[49,50] Conversely, when body weight is reduced by restricting food intake, energy

SCIENCE APPLIED

Leptin: Discovery of an Obesity Gene

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

A discovery made by Rockefeller University physician Jeffrey Friedman and his colleagues in 1994 brought hope to millions of people. Perhaps the cause of obesity had been found, and a cure might be close at hand. Was relief in sight for those who suffer from the physical and social consequences of obesity?

THE SCIENCE

Dr. Friedman's work began with a strain of mice called ob/ob, because they have two copies of a gene that predisposes them to obesity. Ob/ob mice become grossly obese, gaining up to three times the normal body weight. The ob/ob strain arose spontaneously in 1950 in the mouse colony at the Jackson Laboratory in Bar Harbor, Maine. Friedman and his colleagues unraveled the cause for the obesity in this strain of mice when they identified and cloned the gene that was responsible.[51]

Researchers used a series of breeding experiments to localize the gene to a particular stretch of DNA. They then looked to see if any of the genes in this stretch of DNA were expressed in adipose tissue. The search yielded a single gene. Evidence that this gene was involved in the regulation of body weight was obtained by examining the gene and the protein it codes for in the ob/ob mice. Researchers found that this protein, which they named leptin, was either not produced or produced in an inactive form in the obese mice. Soon afterward, a similar gene was identified in humans.

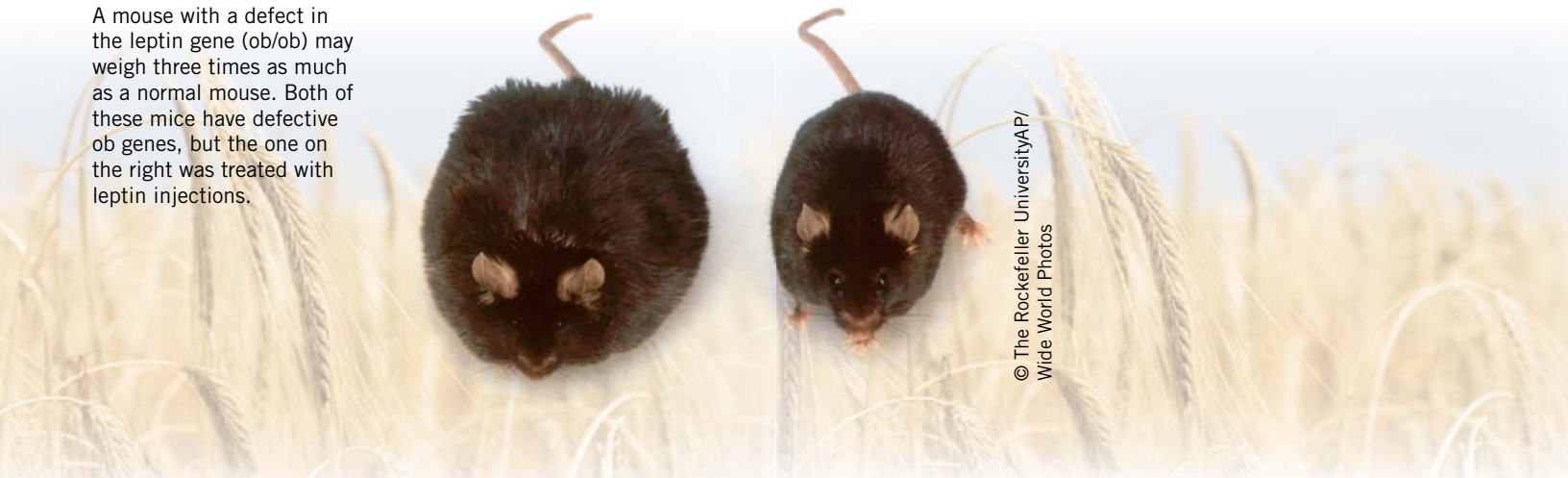
THE APPLICATION

Optimism about the role of the peptide hormone leptin in human obesity was so great that a biotechnology firm (Amgen) paid $25 million for the commercial rights to leptin in the hope that it could be used to treat human obesity. Those hopes grew even higher when Friedman and his colleagues were able to demonstrate that injections of the hormone could restore the genetically obese mice to normal weight (see figure).[52,53] Unfortunately, the role of leptin in human obesity has not been as dramatic. Mutations in this gene are not responsible for most human obesity.[54] In fact, humans with obesity generally have high blood leptin levels.[55] High doses of leptin administered to these humans produce only modest weight loss.[56]

The leptin receptor—a protein in the brain to which leptin must bind to produce weight reduction—was also identified.[57] The fact that humans who are obese have high levels of leptin suggested that the cause of human obesity might involve an abnormality in leptin receptors. If leptin receptors were defective, the leptin produced would have no place to bind and would not be able to signal mechanisms to promote weight reduction. Thus far, however, defective leptin receptors have not been found to be an important cause of human obesity.[58]

Continued study of the role of leptin in obesity has confirmed that it is an important signal involved in the long-term regulation of body fat, but it does not act alone. Many steps, involving many genes, occur between the production of leptin in adipose tissue and alterations in food intake and energy expenditure that are mediated by the brain. Researchers have discovered about a dozen peptides that interact with leptin in the brain to control appetite.[59]

Despite the fact that the identification of leptin has not produced a cure for human obesity, its discovery energized the field of obesity research. This discovery was an important advance in our understanding of the genetics of body-weight regulation. Continued work will someday answer the questions that remain about why some of us are obese and some of us are lean.


© The Rockefeller UniversityAP/ Wide World Photos

A mouse with a defect in the leptin gene (ob/ob) may weigh three times as much as a normal mouse. Both of these mice have defective ob genes, but the one on the right was treated with leptin injections.

expenditure decreases to conserve energy and promote weight gain.[32] These changes in the amount of energy expended in response to changes in circumstance, such as over- or undereating, changes in environmental temperature, or trauma, are referred to as **adaptive thermogenesis**. Genetic variations in the adaptive response to overeating may help explain why some people gain weight more easily than others.

adaptive thermogenesis The change in energy expenditure induced by factors such as changes in ambient temperature and food intake.

Futile Cycling Several biochemical mechanisms have been proposed to explain adaptive thermogenesis. One is substrate cycling or futile cycling, which wastes energy by allowing opposing biochemical reactions to occur simultaneously. For example, if a molecule is formed by a reaction that uses ATP, and then is quickly broken down again, energy is consumed, but there is no net change in the number of molecules in the body and therefore no storage of energy as fat.

Brown Adipose Tissue A second way that excess energy might be dissipated is by separating or uncoupling the electron transport chain from the production of ATP. When this occurs, energy is lost as heat rather than being used to produce ATP. For example, the increase in energy expenditure that occurs when mice are injected with leptin is believed to be due to the stimulation of receptors on a specialized type of adipose tissue called **brown adipose tissue**. Brown adipose tissue can waste energy as heat. This tissue contains many more mitochondria than regular white adipose tissue, and these mitochondria can be uncoupled from the electron transport chain, allowing the energy in food to be released as heat. In rats, brown adipose tissue generates heat to prevent weight gain during overfeeding and to provide warmth when the ambient temperature is low. Studies in humans suggest that the amount of brown adipose tissue may play a role in obesity. High BMI and body fat are associated with low levels of brown adipose tissue, and brown adipose tissue activity has been found to be lower in men who are overweight or obese than in lean men. [60,61]

brown adipose tissue A type of fat tissue that has a greater number of mitochondria than the more common white adipose tissue. It can waste energy as heat.

Some People Expend Less Energy in Physical Activity Activity burns calories; this is true whether the activity is planned exercise or NEAT (nonexercise activity thermogenesis) activities such as housework, walking between classes, fidgeting, and moving to maintain posture. Some people may gain weight more easily because they inherit a tendency to expend less energy in activity. Even if they spend the same amount of time as a lean person in planned exercise, their total energy expenditure may be lower because they expend less energy for NEAT activities (Figure 7.24).[62] In a study that overfed normal-weight individuals, some subjects were able to limit their weight gain by increasing their energy expenditure; those who gained the least weight had the greatest levels of involuntary activity.[63] The mechanisms that allow some people to increase NEAT activity while others remain lethargic are still not understood.

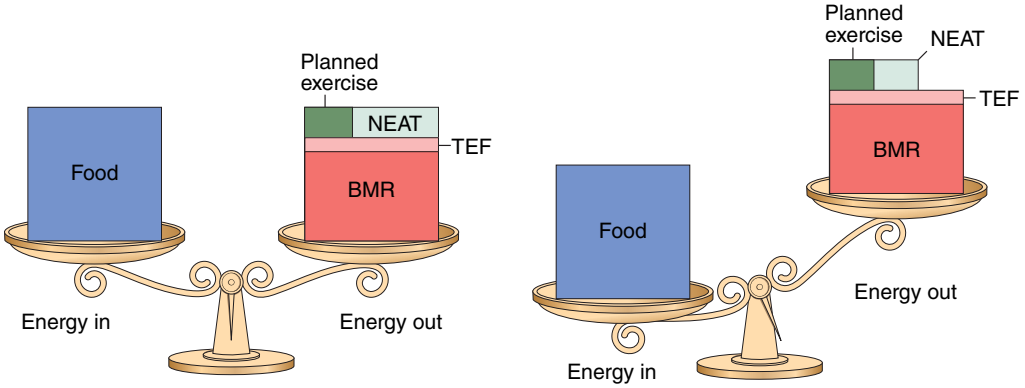


FIGURE 7.24 NEAT in obese vs. lean individuals
The number of calories a person expends in NEAT can affect that person's body weight. Person 1 (illustrated by the scale on the left) is weight stable. She eats the same number of calories as she burns per day. Person 2 (illustrated by the scale on the right) is gaining weight. She eats the same number of calories as person 1 and burns the same number of calories for BMR, TEF, and planned exercise, but her total energy expenditure is lower because she burns fewer calories through NEAT.

7.6 Weight Management

LEARNING OBJECTIVES

- Evaluate an individual's weight and medical history to determine if weight loss is recommended.
- Discuss the recommendations for the rate and amount of weight loss.
- Name the three components of an ideal weight-management plan.
- Describe methods for addressing the population-wide obesity crisis.

Weight management means keeping weight in the range that reduces health risks. For some people, it requires maintaining a balance between energy intake and energy expenditure by making healthy food choices, controlling portion sizes, and maintaining an active lifestyle to avoid weight gain as they age. For many others, it may mean making major lifestyle changes in order to reduce their weight into the healthy range and keep it there. And for some, it may mean working to increase weight and then keep it in the healthy range.

Who Would Benefit from Weight Loss?

Not everyone who is a few pounds overweight needs to lose weight to stay healthy. The risks associated with overweight and obesity are related to the degree of excess weight or fat, the distribution of the excess body fat, the presence of other diseases or risk factors that often accompany excess body fat, and the age and life stage of the individual.

Assessing the Risk of Excess Weight To determine if someone should lose weight, the first step is to evaluate the person's current weight and weight history and review his or her medical conditions (Figure 7.25).[64] A BMI above the healthy range generally means that weight loss would improve long-term health, but this is not always the case. Some people with a high BMI,

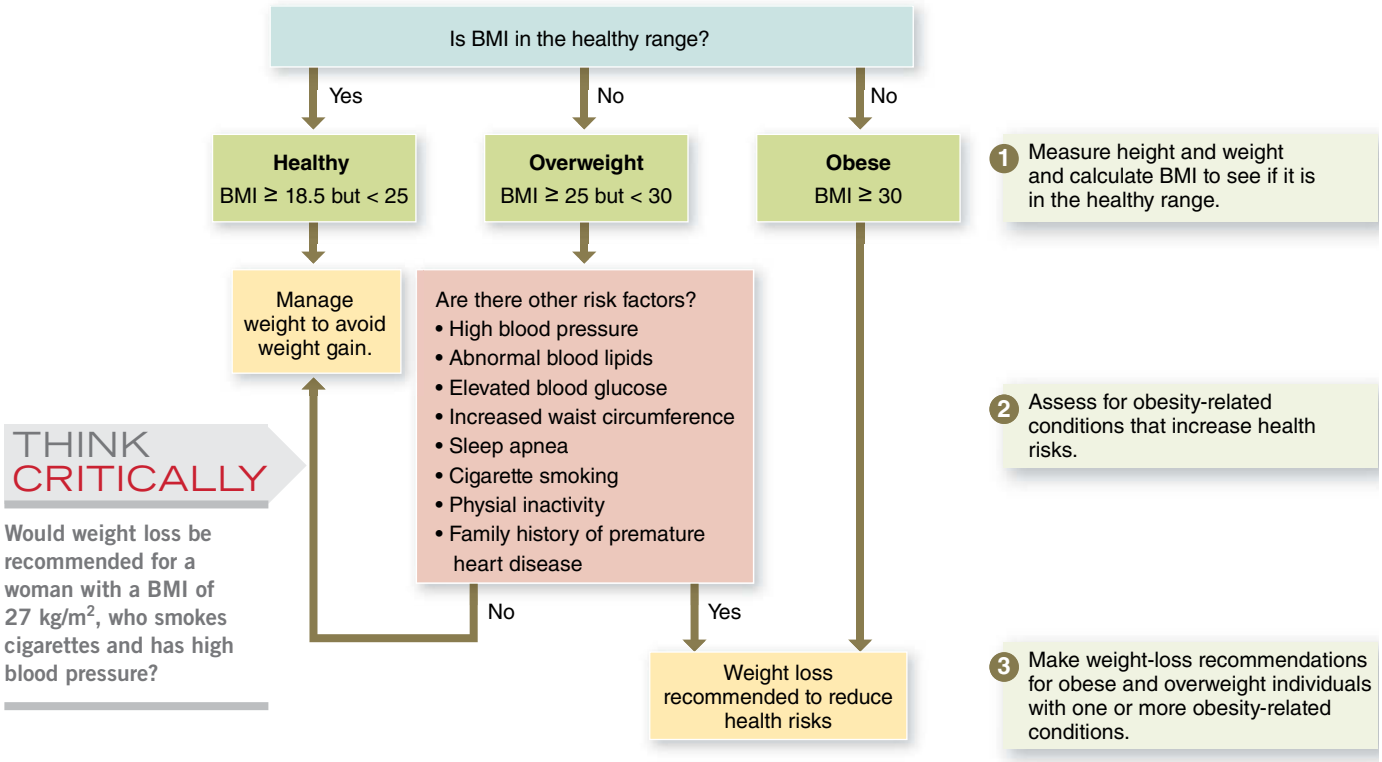


FIGURE 7.25 Determining who would benefit from weight loss
This decision tree can be used to determine whether someone would benefit from weight loss.[64]

such as weightlifters, may have a large amount of muscle mass but not more body fat than is recommended and some may have a high BMI, but low levels of visceral fat and obesity-related health conditions.[22] A key factor in whether or not weight loss is recommended is the presence of obesity-related risk factors. A person whose BMI is above the healthy range and has obesity-related risk factors will probably benefit from weight loss. A family history of these obesity-related conditions is also a consideration in determining whether or not weight loss is recommended. On the other hand, a person who has a BMI in the overweight range (25 to 29.9 kg/m^2) but has none of the obesity-related risk factors and has a healthy lifestyle may not achieve any health benefit from losing weight. For example, a woman with a BMI of 28 kg/m^2 and a waist circumference of 33 in., whose blood pressure and cholesterol levels are normal and who exercises regularly, would not reduce her health risks by losing weight. For this individual, weight management may mean simply preventing further weight gain (see Figure 7.25).

Consider Life Stage Recommendations about weight loss are affected by life stage; at certain times of life, weight loss is not recommended. For example, the goal for a growing child who is overweight is often to maintain weight rather than lose weight. A severe reduction in intake can interfere with growth, so energy restrictions should be relatively mild with a focus on nutrient-dense foods and increasing physical activity. Slowing weight gain while continuing growth in height will bring BMI into the healthy range. For children who are obese, a weight-loss regimen may be needed (see Chapter 15).

Weight-loss diets are also not recommended during pregnancy. Even women who are overweight or obese at the start of pregnancy should gain at a slow, steady rate over the course of pregnancy. A weight-loss program can be initiated after the baby is born and the mother has recovered (see Chapter 14). Slow weight loss is appropriate during lactation, but rapid weight loss can decrease milk production.

The treatment of obesity in older adults is controversial because a few extra pounds may provide a reserve that is beneficial in the event of a long-term illness. In addition, the risks associated with excess body fat are lower for older adults than they are for younger adults and restrictive diets may exacerbate age-related loss of muscle and bone.[65,66] Despite this, weight loss, particularly when achieved through an increase in physical activity, can enhance day-to-day functioning and improve cardiovascular disease risk factors.[67] Weight-training activities are an important part of a weight-loss program in the elderly (see Chapter 16).

Weight-Loss Goals

The medical goal for overweight people is to manage their weight to reduce the health risks associated with being overweight. Managing weight in this case means to slowly bring weight to a level that will reduce health risks. For most people, a loss of 3 to 5% of body weight will significantly reduce disease risk, and greater weight loss can result in more health benefits.[64] The general recommendation is to reduce body weight by 5 to 10% over a period of about six months. This amount of weight loss can lower blood pressure, reduce the risk of developing type 2 diabetes, and improve blood lipid profiles. After this initial weight loss, risk factors can be reassessed to determine the need for additional weight loss.

To ensure that most of the weight lost is fat and not lean tissue, the weight should be lost slowly at a rate of between 0.5 and 2 lb per week. If weight is lost more rapidly, the loss is less likely to be maintained, and the additional loss will be from fluid, glycogen, and muscle protein. Since a pound of body fat provides about 3500 kcal, losing a pound of adipose tissue requires decreasing intake and/or increasing expenditure by this amount. To lose a pound in a week, you would need to tip your energy balance by about 500 kcal each day. This could mean adding 500 kcal of physical activity, reducing intake by 500 kcal, or some combination of the two. The arithmetic is simple, but achieving and maintaining weight loss is not easy.

Why Maintaining Weight Loss Is Challenging

Most people who lose weight regain what they have lost. This is due in part to environmental and emotional motivators to increase food intake and reduce the inclination to exercise, but there are also physiological reasons. One of the mechanisms that makes losing weight and maintaining the loss difficult is the effect weight loss has on metabolic rate. As weight decreases, so does resting metabolic rate

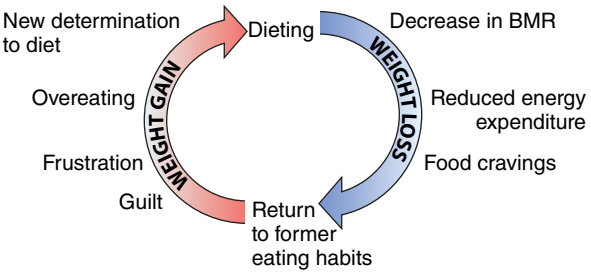


FIGURE 7.26 Weight cycling
Drastic reductions in food intake lead to rapid weight loss but also cause a drop in BMR and may result in reduced activity and increased food cravings. These effects make it difficult to maintain the weight loss and contribute to weight cycling.

because metabolic efficiency is increased and body mass is reduced.[31,32] The lower body mass decreases basal metabolic rate because there is less lean tissue to maintain. Lower body mass also decreases the amount of energy expended during physical activity because less total mass must be moved. Therefore, after weight loss the same amount of activity, whether planned exercise or NEAT, uses less energy.[31] These factors make maintenance of the weight loss more difficult.

weight cycling or **yo-yo dieting** The repeated loss and regain of body weight.

Because weight maintenance is difficult, many people repeatedly lose and then regain the weight they have lost. Repeated cycles of weight loss and regain, referred to as **weight cycling** or **yo-yo dieting**, have been found to increase the proportion of fat to lean tissue and decrease the likelihood that future attempts at weight loss will be successful (Figure 7.26).[68] To prevent weight cycling, weight-loss programs need to focus on long-term weight management.

An Ideal Weight-Management Program

VIDEO

An ideal weight-loss program involves reducing energy intake, increasing physical activity, and changing behavior to promote weight loss and long-term weight management (see **How to Choose: Weight Management**). Compared to diet alone, combining diet, activity, and behavior modification results in greater short-term weight loss and better weight maintenance in the long term.[64]

Decreasing Energy Intake To promote weight loss without compromising nutrient intake, an individual's diet must be low in energy but provide all the nutrients the body needs. Nutrient density becomes more important as energy intake is reduced. The Dietary Guidelines suggest

HOW TO CHOOSE	Weight Management
Balance your intake and output	
• Know your calorie needs and monitor what you eat.	
• Weigh yourself frequently; if your weight goes up, cut down your calories.	
• When you add dessert, add extra activity.	
• Watch your alcohol consumption, and count the calories in alcoholic beverages.	
Cut down on calories	
• Replace your sugar-sweetened soft drink with a glass of water with lemon.	
• Cut your spreads in half; put half your usual amount of mayo or butter on your bread.	
• Count your chips – eating right from the bag or box leads to overconsumption.	
• Choose a plain burger and a small order of fries when you have fast food.	
• When you eat out, share an entree with a friend or take some home for lunch the next day.	
Don't get too hungry	
• Eat breakfast—you'll eat less later in the day.	
• Fill up on fiber—eat your salad and veggies first.	
• Drink water between and with meals	
• Plan your snacks—keep cut up, ready-to-eat vegetables and fruit handy so you skip the chips.	
Increase activity	
• Go for a bike ride.	
• Try bowling or miniature golf instead of watching TV on Friday nights.	
• Take a walk during your lunch break or after dinner.	
• Play tennis; you don't have to be good to get plenty of exercise.	
• Boost your NEAT calories—small changes such as getting off the bus early or parking at the back of the lot all add up.	

reducing empty calories from added sugars, solid fats, and alcohol.[5] Even when choosing nutrient-dense foods, it is difficult to meet nutrient needs with intakes of less than 1200 kcal/day; therefore, dieters consuming less than this should take a multivitamin and mineral supplement. Medical supervision is recommended if intake is 800 kcal/day or less.

Increasing Physical Activity Physical activity is an important component of any weight-loss or weight-management program. Exercise promotes fat loss and weight maintenance. It increases energy expenditure, so if intake remains the same, energy stored as fat is used for fuel. An increase in activity of 200 kcal five times a week will result in the loss of 1 lb in about 3½ weeks. In addition to increasing energy expenditure, physical activity also promotes muscle development. This is important for promoting weight loss because muscle is metabolically active tissue. Increasing muscle mass helps to prevent the drop in metabolic rate that occurs as body weight decreases. In addition to promoting and maintaining weight loss, physical activity improves overall fitness and relieves boredom and stress.

To promote health and prevent gradual weight gain, adults should engage in 150 minutes of moderate activity per week.[5,69] Some individuals may need the equivalent of 60 minutes of moderate exercise per day to achieve and maintain a healthy weight. Data that track people who have lost weight and maintained the loss for over five years indicate that they exercise, on average, about an hour a day.[70] Exercise guidelines and the benefits of exercise are discussed further in Chapter 13.

Modifying Behavior People tend to think of weight loss as something they can accomplish by going on a diet. When the weight is lost, they go off the diet. The problem is that when their eating patterns return to what they were previously, they regain the weight. This "on a diet, off a diet" pattern may allow you to look good for spring break, but it's not what is needed for long-term weight management. To manage your weight at a healthy level, you need to establish a pattern of food intake and exercise that allows you to enjoy foods and activities you like without your weight climbing. It should be a pattern that you can comfortably adopt for life.

Changing food consumption and exercise patterns requires identifying the patterns that led to weight gain and replacing them with new ones to promote and maintain weight loss. This can be accomplished through a process called **behavior modification**, which is based on the theory that behaviors involve (1) antecedents or cues that lead to the behavior, (2) the behavior itself, and (3) consequences of the behavior. These are referred to as the ABCs of behavior modification.

behavior modification A process used to gradually and permanently change habitual behaviors.

The first step in a behavior modification program is to identify cues that lead to eating. You can do this by keeping a log of everything you eat or drink, where you were when you ate, what else you were doing at the time, and what motivated you to eat at that time. Then by analyzing this log, you can see what prompted you to eat excessive amounts or high-calorie foods. For instance, sitting in front of the television and mindlessly demolishing a bag of potato chips may cause you to overeat and then feel bad because you consumed the extra calories (Figure 7.27).

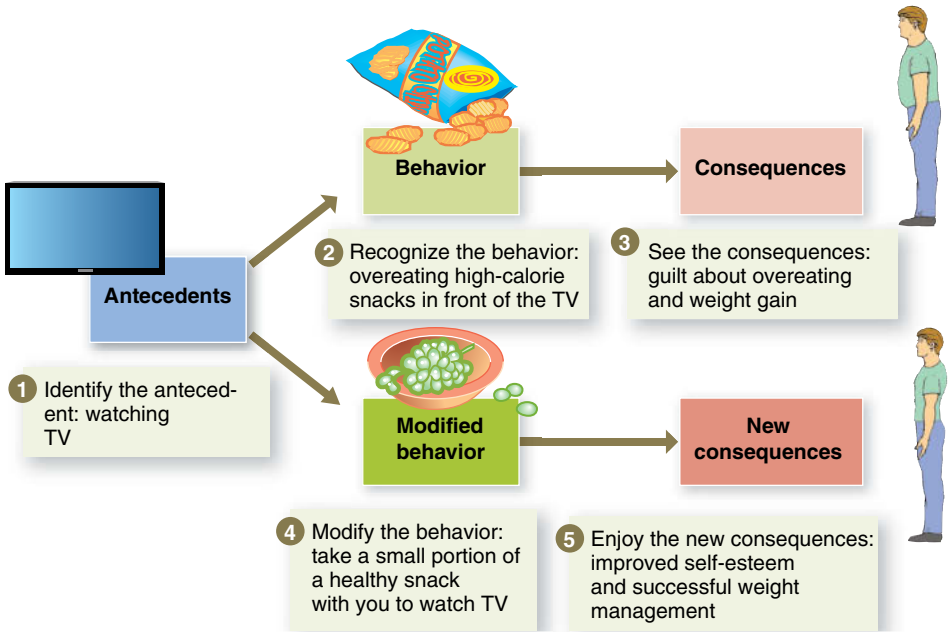


FIGURE 7.27 The ABCs of behavior modification

In this case, the antecedent is watching TV, the behavior is mindlessly eating the chips, and the consequence is feeling remorse and gaining weight. The key to modifying this behavior is to recognize the antecedent, change the behavior, and replace the negative consequence with a positive one. In this example, not taking food with you to the television, or taking only the portion of food you want to consume, eliminates the antecedent and the behavior. The consequence is that you have consumed only the food you planned, you do not gain weight, and you feel a sense of accomplishment.

Managing America's Weight

Although successful weight management ultimately depends on an individual's choices, changes in what has been termed our *obesogenic environment* can reduce obesity by helping all Americans improve their food choices, reduce serving sizes, and increase their physical activity.[71] Food manufacturers and restaurants can help improve our food environment by packaging foods in smaller portions. Restaurants can help by offering healthier choices and smaller portions. Communities can help increase activity by providing parks, bike paths, and other recreational facilities for people of all ages. Businesses and schools can contribute by offering more opportunities for physical activity at the workplace and during the school day.

Even small changes, if they are consistent, can arrest the increase in obesity in the population. It has been estimated that a population-wide shift in energy balance of only 100 kcal a day, the equivalent of walking a mile or cutting out a scoop of ice cream, would prevent further weight gain in the majority of the population (see **Critical Thinking: Balancing Energy: Genetics and Lifestyle**).[72]

Suggestions for Weight Gain

As difficult as weight loss is for some people, weight gain can be equally elusive for underweight individuals. The first step toward weight gain is a clinical evaluation to rule out medical reasons for low body weight. This is particularly important when weight loss occurs unexpectedly. If the low body weight is due to low intake or high expenditure, gradually increasing consumption of energy-dense foods is suggested. More frequent meals and high-calorie snacks such as nuts, peanut butter, or milkshakes between meals can help increase energy intake. Replacing low-calorie fluids like water and diet beverages with fruit juices and milk may also help.

To encourage a gain in muscle rather than fat, strength-training exercise should be a component of any weight-gain program. This approach requires extra calories to fuel the activity needed to build muscles. These recommendations apply to individuals who are naturally thin and have trouble gaining weight on the recommended energy intake. This dietary approach may not promote weight gain for those who limit intake because of an eating disorder (see Focus on Eating Disorders).

7.7 Approaches to Weight Loss

LEARNING OBJECTIVES

- Compare the benefits of a diet that uses a food group system with one that relies on prepared meals and drinks.
- Describe how the proportions of macronutrients relate to the effectiveness of a weight-loss diet.
- Explain how weight-loss drugs and surgery can promote weight loss.
- Discuss when weight-loss drugs or surgery might be considered appropriate.

Anyone who has battled a weight problem has probably dreamed of a solution that would melt away the pounds without requiring him or her to measure every morsel that passes his or her lips. People desperate to lose weight are prey to all sorts of diets and products that promise quick fixes. They willingly eat a single food for days at a time, select foods based on special

CRITICAL THINKING

Balancing Energy: Genetics and Lifestyle

Tim Mantoani/Masterfile

Aysha was always slightly overweight. Because her parents are both obese, no one was surprised. During her freshman year at college, she noticed that her friends ate and spent their free time differently than she did. She decided to make some changes. Aysha, now 23 years old, is 5 feet 4 in. tall and weighs 155 lb.

▼

What is her BMI? Is it in the healthy range?

By recording and analyzing her food intake for three days, Aysha determines that her typical intake is 2450 kcal/day. By keeping an activity log, she estimates that she gets 30 minutes of moderate-intensity activity per day. This puts her activity level in the "low-active" category.

▼

How does Aysha's EER compare with her intake? Is she in energy balance?

Aysha has heard that changing her energy balance by even 100 kcal a day can help manage weight. To increase her activity level to the active category, she begins walking with her roommate three days a week and enrolls in an aerobic class two nights a week.

▼

If she maintains the active activity level, how long will it take her to lose 10 lb (assume 3500 kcal/lb)?

To cut her energy intake, Aysha checks the calories provided by the foods she typically eats between meals.

▼

FOOD	ENERGY (KCAL)
Glazed doughnut twist, 5 in.	490
Potato chips, 2 oz	300
Fruit drink, 20 oz	240
Nachos with cheese, 1 cup	258
Tombstone 4-Meat pizza, 1 slice	400
Peanut butter chocolate granola bar	190
Breyers Reese's ice cream, 1 cup	340
Snickers candy bar, 4 oz	543

CRITICAL THINKING QUESTIONS

- **Suggest an alternative for each of these snacks that would cut at least 100 kcal.**
- **As Aysha begins to lose weight, she wonders if her weight problem is due to the genes she inherited or her lifestyle. What would you tell her?**

iProfile Use iProfile to find a snack for Aysha that would provide less than 100 kcal.

fat-burning qualities, and consume odd combinations at specific times of the day. Most diets, no matter how outlandish, do promote weight loss, at least in the short term, because they reduce energy intake. When weight-loss diets fail, medications and surgery can be acceptable weight-management tools for high-risk individuals. The true test of the effectiveness of a weight-loss diet, drug, or surgical procedure is whether those who use it can safely maintain their weight loss over the long term.

Methods to Reduce Energy Intake

An ideal diet is one that is part of a weight-management program that promotes weight loss and then maintenance of that loss over the long term. To be successful, the program needs to encourage

changes in the lifestyle patterns that led to weight gain. When selecting a program, look for one that is based on sound nutrition and exercise principles; suits your individual food preferences; promotes long-term lifestyle changes; and meets your needs in terms of cost, convenience, and time commitment (Table 7.5). While quick fixes are tempting, if the program's approach is not one that can be followed for a lifetime, it is unlikely to promote successful weight management.

The following sections discuss some of the more common methods for reducing calorie intake. The advantages and disadvantages of a number of popular diets and weight-management programs are given in Table 7.6.

TABLE 7.5 Distinguishing between Healthy Diets and Fad Diets

A healthy diet . . .	A fad diet . . .
Promotes a healthy dietary pattern that meets nutrient needs, includes a variety of foods, suits food preferences, and can be maintained throughout life.	Limits food selections to a few food groups or promotes rituals such as eating only specific food combinations. As a result, it may be limited in certain nutrients and in variety.
Promotes a reasonable weight loss of 0.5 to 2 lb/week and does not restrict energy intake to under 1200 kcal/day.	Promotes rapid weight loss of much more than 2 lb/week. Restricts energy intake to less than 1200 kcal/day.
Promotes or includes physical activity.	Advertises weight loss without the need to exercise.
Is flexible enough to be followed when eating out and includes foods that are easily obtained.	May require a rigid menu or avoidance of certain foods or may include "magic" foods that promise to burn fat or speed up metabolism.
Does not require costly supplements.	May require the purchase of special foods, weight-loss patches, expensive supplements, creams, or other products.
Promotes a change in behavior. Teaches new eating habits. Provides social support.	Does not recommend changes in activity and eating habits, recommends an eating pattern that is difficult to follow for life, or provides no support other than a book that must be purchased.
Is based on sound scientific principles and may include monitoring by qualified health professionals.	Makes outlandish and unscientific claims, does not support claims that it is clinically tested or scientifically proved, claims that it is new and improved or based on some new scientific discovery, or relies on testimonials from celebrities or connects the diet to trendy places such as Beverly Hills.

TABLE 7.6 Pros and Cons of Weight-Loss Diets

Diet	Approach	Pros	Cons
Weight Watchers	Low calorie; social support	Inexpensive; flexible	
Jenny Craig	Low calorie; prepackaged foods; weekly counseling	Convenient	Expensive; relies on purchase of special foods
SlimFast	Low calorie; liquid formula; two meals per day	Convenient	Relies on purchase of special foods; no social support
HMR (Health Management Resources)	Meal replacement	Rapid weight loss	Severe calorie restriction initially; difficult to follow if eating out
Paleo	Low carbohydrate	Simple to follow	Eliminates several food groups; no social support
Body Reset	Train your body to burn calories faster	Rapid weight loss	Based on unsound science; difficult to follow; no social support
Flat Belly diet	High monounsaturated fat; specific foods at specific times	Safe; nutritious	Complicated to follow; no social support
Zone	Controlling blood sugar controls weight	Inexpensive; flexible	Based on questionable principles; no social support
Dukan diet	High protein	Promotes quick weight loss	Lots of very specific rules; no social support
Biggest loser	Healthy food and regular exercise	Safe; easy to follow; effective in the short term	Poor long-term success
NutriSystem	Prepackaged meals	Rapid weight loss	No social support; does not promote long-term behavior change
Glycemic index diet	Promotes good carbs	Inexpensive	Provides little guidance beyond carbs; no social support
Atkins diet	Very low carbohydrate	Inexpensive; rapid initial weight loss	Difficult to follow in the long term; no social support
South Beach diet	Low carbohydrate	Inexpensive; heart healthy	Initial weight loss is mostly water; no social support

Ken Karp

FIGURE 7.28 Preportioned meals and beverages Frozen prepared meals, meal replacement bars, and drinks are popular with dieters because the food is preportioned and no decisions or measuring is required.

Food Groups Diets that are based on food groups instruct the dieter to select a certain amount of food from specific food groups in order to limit calorie intake while providing an adequate balance of nutrients. For example, MyPlate uses a food group system to recommend calorie levels while maintaining a healthy pattern. Entering your information into SuperTracker will give you a diet plan that recommends the number of servings from each of the food groups that will promote weight loss. The Choice (Exchange) Lists (see Table 7.2) and Weight Watchers are other examples of food group systems that can be used to manage calorie intake. Food group programs teach meal-planning skills that are easy to apply away from home and can be used over the long term.

Prepackaged Meals and Formulas It is easier to eat less when someone else decides what you're having and puts appropriate portions of that food in front of you. This is the idea behind diet plans that sell prepackaged meals or drinks designed to replace some or all of your usual meals (Figure 7.28). They can make reducing intake easy because they eliminate the problem of choosing appropriate portions of low-calorie foods. Many of the liquid weight-loss diets that are available over the counter recommend a combination of food and the liquid formula to provide about 800 to 1200 kcal/day. These formula plans promote weight loss as long as the foods eaten with them are low in calories. Programs that rely exclusively on liquid formulas have high dropout rates and poor long-term weight-maintenance results. These are not recommended without medical supervision.

It is easy to use prepackaged meals and formulas as long as you are not eating out, but they can be expensive and are not practical over the long term. Because all foods are provided, they do not change eating habits or teach the food-selection skills needed to make a long-term lifestyle change.

Very-Low-Calorie Diets A **very-low-calorie diet** is defined as one that provides fewer than 800 kcal/day. These diets replace food with liquid shakes or meal replacement bars. They are medically supervised and typically administered through hospitals or clinics. One type of very-low-calorie diet is the **protein-sparing modified fast**, which provides a high proportion of protein but little energy. The concept behind this is that the protein in the diet will be used to meet the body's protein needs and will, therefore, prevent excessive loss of body protein.

very-low-calorie diet A weight-loss diet that provides fewer than 800 kcal/day.

protein-sparing modified fast A very-low-calorie diet with a high proportion of protein; designed to maximize the loss of fat and minimize the loss of protein from the body.

Very-low-calorie diets promote rapid weight loss; initial weight loss is 3 to 5 lb/week. This can provide a psychological boost and motivate the dieter to continue losing weight; however, in most cases, much of this initial weight loss is from water loss. Once the initial water loss ends, weight loss slows. The dieter's basal metabolism slows to conserve energy, and physical activity decreases because the dieter often does not have the energy to continue his or her typical level of activity.

Very-low-calorie diets are no more effective than other methods of weight loss in the long term and carry more risks. At these low-energy intakes, body protein is broken down and potassium is excreted. Depletion of potassium can result in an irregular heartbeat and is potentially deadly. Other side effects include gallstones, fatigue, nausea, cold intolerance, light-headedness,

nervousness, constipation or diarrhea, anemia, hair loss, dry skin, and menstrual irregularities. These diets are not recommended for people with a BMI of less than 30 kg/m^2, children, adolescents, pregnant or breast-feeding women, or those with severe medical problems.[73] Since 1984, the FDA has required that all very-low-calorie diet formulas carry a warning that they can cause serious illness and should be used only under medical supervision.

Changing the Proportion of Macronutrients Many diets promote weight loss by altering the proportion of macronutrients in the diet. In all of these diet plans, whether low fat, low carbohydrate, or high protein, weight is lost because energy intake is reduced relative to expenditure. All claim to be the best way to lose weight, but which is really best depends on the individual dieter.

Low-Fat Diets Low-fat weight-loss diets have been popular for decades. Fat is high in energy: 9 kcal/g—almost twice as much as either carbohydrate or protein. Low-fat diets therefore tend to provide a greater volume of food for less energy than a diet with more fat. Because people have a tendency to eat a certain weight or volume of food, if that food is low in fat it will contribute fewer calories. But a low-fat diet that doesn't restrict calories will not promote weight loss.

Problems with low-fat diets occur when people equate low fat with "healthy" or "low calorie." In the 1990s, the food industry flooded the market with reduced-fat cookies and cakes. These foods were low in fat but not in energy, so when consumed in large amounts they caused weight gain, not weight loss. A healthy low-fat diet includes lots of fresh fruits and vegetables, which are low in fat and calories and high in nutrients. As with any diet, effectiveness is related more to adherence to the diet than to the type of diet (Figure 7.29).

Low-Carbohydrate Diets If you cut out the pasta and potatoes you will lose weight, right? The Atkins diet, South Beach diet, Sugar-Busters, Calories Don't Count, Scarsdale diet, and Zone diet are just a few of the low-carbohydrate weight-loss diets that have been promoted during the past 50 years. Low-carbohydrate diets are all based on the premise that a high-carbohydrate intake causes an increase in insulin levels, which promotes the storage of body fat. Restricting carbohydrate intake is hypothesized to reduce insulin, thereby reducing fat storage and promoting fat loss.

Very restrictive low-carbohydrate diets prohibit foods such as breads, grains, and fruits and limit vegetable intake while allowing unlimited quantities of meat and high-fat foods that are low in carbohydrate. These diets cause a rapid initial weight loss because when carbohydrate intake is low, glycogen stores, along with the water they hold, are lost quickly. Ketones are produced because fat is not completely broken down in the absence of carbohydrate. Excretion of these ketones in the urine causes further water loss. Weight loss continues on very-low-carbohydrate diets because total energy intake is reduced. The high-protein content of these diets is satiating and elevated blood ketone levels further suppress appetite, making it easier to reduce food intake. In addition, these diets limit food choices to such an extent that the monotony results in a spontaneous reduction in energy intake.[74]

Low-carbohydrate diets with more moderate carbohydrate restrictions (<45% of energy from carbohydrate is considered low-carb) allow low-carbohydrate vegetables, legumes, fruit,

THINK CRITICALLY

These two meals contain the same number of calories. Which do you think would be more satiating? Why?

FIGURE 7.29 Low-fat vs. low-carbohydrate diets
Low-fat diets can include high-carbohydrate foods like pasta and potatoes, but quantities must be limited to avoid exceeding calorie limits. Low-carbohydrate diets exclude all grains and starchy vegetables, but do not mandate limiting calories. Which diet is more effective in the long term depends on an individual's preferences and ability to comply long term.

and whole grains. These foods are high in fiber and do not increase blood glucose and insulin levels nearly as much as refined carbohydrates such as white flour and sugar.

In general, low-carbohydrate diets are effective for weight loss and have been shown to improve blood pressure, blood glucose, and blood lipid levels.[75] However, the impact these diets have on long-term health depends on how severe the carbohydrate restriction is and on the sources of carbohydrate, fat, and protein included in the diet. Very-low-carbohydrate diets can be high in red meat, which is high in saturated fat, and low in fruits, vegetables, whole grains, and milk. Studies show that after a year, LDL cholesterol was increased in subjects consuming this type of diet.[76] There is also concern that the high intake of meat may contribute to an increased risk of cancer, particularly colon cancer.[77,78] Low intakes of fruits, vegetables, and whole grains could affect health by reducing intakes of essential nutrients, phytochemicals, and fiber.

High-Protein Diets Many popular weight-loss diets focus on protein, promoting a protein intake of 25% or more of calories. The high protein content promotes satiety and preserves muscle mass. High-protein diets have also been found to be energetically beneficial because they cause less of a decrease in energy expenditure than low-fat or high-carbohydrate diets.[79,80] High-protein diets also increase energy expenditure because the body must use more energy to process the protein it consumes than it uses for either fat or carbohydrate.[80] Despite these benefits, this approach has not been shown to be more effective for weight loss than other calorie-restricted diets.[81,82] A healthy high-protein dietary pattern uses poultry, fish, nuts, and legumes as protein sources and limits red meat and processed meats (See Chapter 6, *Debate: The Highs and Lows of High-Protein Diets*).

Weight-Loss Drugs and Supplements

An ideal drug for the treatment of obesity would permit an individual to lose weight and maintain the loss, be safe when used for long periods of time, have no side effects, and not be addictive. Many attempts have been made to develop such a drug, but weight-loss drugs still carry risks. For example, in 1996, approximately 18 million prescriptions were written for a drug combination called fen-phen (fenfluramine and phentermine) that was being used to reduce food intake. The following year, it was linked to serious heart-valve damage. As a result, fenfluramine and the related drug dexfenfluramine were withdrawn from the market.[83]

Prescription and Nonprescription Drugs Some of the prescription drugs available for the treatment of obesity work by reducing food intake. One of these (lorcaserin [Belviq]), increases the sense of fullness by affecting the activity of brain neurotransmitters; two others (phentermine [Adipex] and phendimetrazine [Bontril]) are stimulants that reduce appetite. Also available are drugs, such as orlistat (Xenical), that decrease energy intake by reducing the amount of fat absorbed from the GI tract.

Prescription drugs are recommended along with diet and exercise for those with a BMI $\geq$ 30 kg/m^2 or a BMI $\geq$ 27 kg/m^2 with one or more obesity-related risk factors.[64] Weight-loss medication may also be considered for anyone who would benefit from weight loss but who has not been able to lose enough weight through lifestyle modification to improve health. As with any treatment, the risks should be weighed against the benefits before starting a medication for weight loss. One of the major disadvantages of drug treatment is that, even if the drug promotes weight loss in the short term, the weight is regained when the drug is discontinued.

Like prescription drugs, nonprescription medications sold over the counter to promote weight loss are regulated by the FDA and must adhere to strict guidelines regarding the dose per pill and the effectiveness of the ingredients. Only a limited number of substances have been approved by the FDA for sale as nonprescription weight-loss medications. One of these is a nonprescription version of orlistat, called Alli (**Figure 7.30**). It acts by disabling the enzyme lipase, preventing triglycerides from being digested and absorbed. This cuts the number of calories available to the body, but the fat in the stool may cause gas, diarrhea, and more frequent and hard-to-control bowel movements. As with prescription medications, any weight loss that occurs with over-the-counter weight-loss medications is usually regained when the product is no longer consumed.

Dietary Supplements Hundreds of dietary supplements are available that claim to promote weight loss. As with other dietary supplements, weight-loss supplements are not strictly regulated by the FDA, so their safety and effectiveness may not have been carefully tested. Some products claiming to be weight-loss supplements have been found to contain hidden prescription drugs or

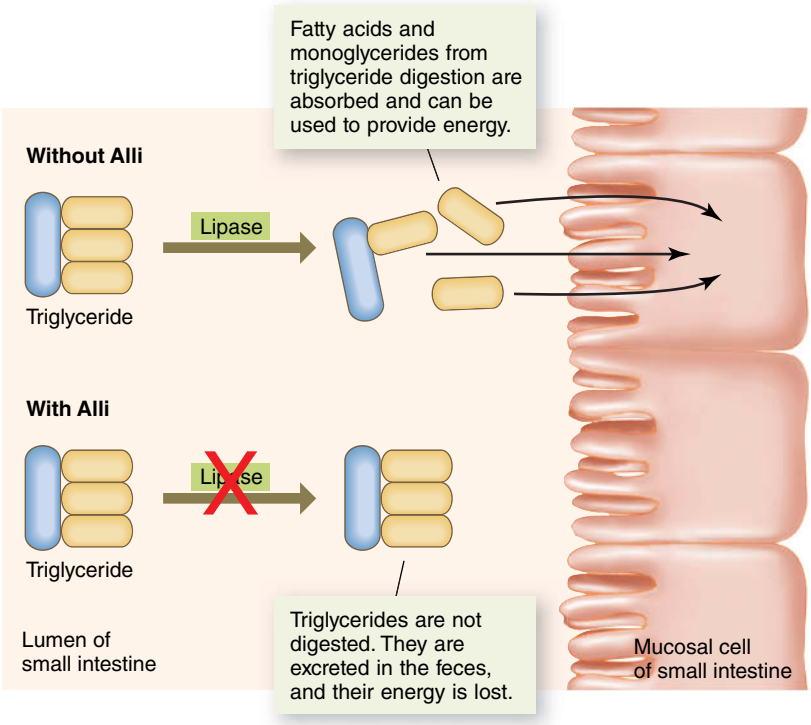


FIGURE 7.30 Alli and fat digestion
Alli is an over-the-counter weight-loss aid that acts by preventing triglyceride digestion.

THINK CRITICALLY

Will Alli be an effective weight-loss aid for someone who eats a low-fat diet?

compounds that have not been adequately studied in humans.[84] It cannot be assumed that a product is safe simply because it is labeled a dietary supplement or as "herbal" or "all natural."

Weight-loss supplements use a variety of approaches to either reduce food intake or increase energy expenditure. Most are ineffective and a few are dangerous. Some are reviewed here and more are addressed in Focus on Dietary Supplements. Weight-loss supplements that contain soluble fiber promise to reduce the amount you eat by filling up your stomach. Although they are safe, their use may contribute to only small amounts of weight loss.[85] Hydroxycitric acid, conjugated linoleic acid, and chromium picolinate are weight-loss supplements that promise to enhance fat loss by altering metabolism so as to prevent the synthesis and deposition of fat. None of these supplements has been shown to be effective for promoting weight loss in humans.[86]

Supplements that boost energy expenditure, often called "fat burners," can be effective for weight loss but have serious and potentially life-threatening side effects. One of the most popular and controversial herbal fat burners is ephedra, a stimulant that increases blood pressure and heart rate and constricts blood vessels. Due to safety concerns, the FDA banned it in 2004. After the ban was instituted, supplement manufacturers began substituting other herbal products, such as bitter orange, that contain similar stimulants and therefore may have similar side effects.[85] Fat burners also typically contain guarana, an herbal source of caffeine. Green tea extract is another popular supplement used to boost metabolism and aid weight loss. Green tea extract is also a source of caffeine as well as phytochemicals called catechins. Studies have shown it to have only a small effect on weight loss in certain populations. Consuming green tea is safe, but green tea extract has been associated with liver damage.[85]

Several supplements cause weight loss by increasing the amount of water lost from the body—either because these supplements are diuretics or because they cause diarrhea. Water loss decreases body weight but does not cause a decrease in body fat. Herbal laxatives found in weight-loss teas and supplements include senna, aloe, buckthorn, rhubarb root, cascara, and castor oil. Overuse of these substances can have serious side effects, including diarrhea, electrolyte imbalances, and potential liver and kidney toxicity.[86]

Bariatric Surgery

A number of surgical procedures are used to promote weight loss. These are referred to as *bariatric surgeries*. They are recommended only for individuals who have a BMI $\geq$ 40 kg/m^2 or a

DEBATE

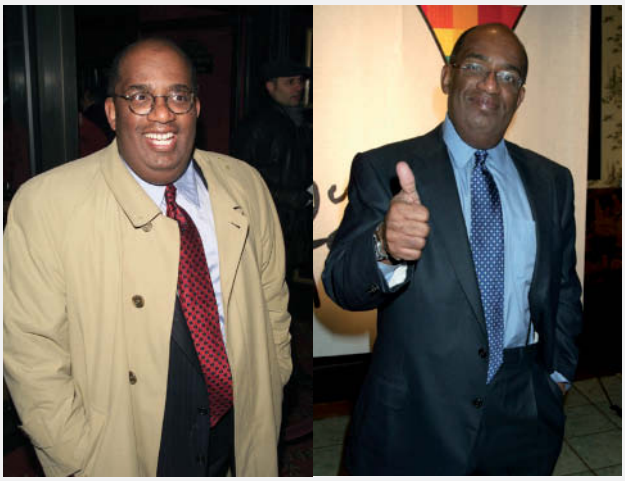
Is Surgery a Good Solution to Obesity?

The medical, social, and financial costs of obesity are well known. So is the fact that eating less and moving more will promote weight loss. However, these conventional methods do not always work. When they fail, is weight-loss surgery, known as bariatric surgery, a good weight-loss option?

Bariatric surgery is becoming increasingly common; during the past decade, there has been a 15-fold increase in the frequency of these procedures.[87] They are effective, and for some they can be lifesaving. When compared with conventional treatment, weight loss was greater at 2 years and at 10 years in those who had bariatric surgery. The incidence and control of type 2 diabetes, hypertension, high blood cholesterol, gastrointestinal reflux disease, and sleep apnea all improved with weight-loss surgery. In addition, quality of life improved in those who had surgery, and medication costs and overall mortality decreased.[88,89]

About 1 in 20 Americans is severely obese and meets the criteria for treatment with bariatric surgery, but only 0.6% of eligible patients have the surgery each year. This is because bariatric surgery is not without costs and complications.[90] Gastric bypass surgery costs about $18,000 to $22,000, and adjustable gastric banding costs about $17,000 to $30,000.[91] Complications are common; although fewer than 1% of patients die during or immediately after surgery, 17% experience adverse events.[92] The major complications, some of which require follow-up surgery, include ulcers, blockage of the opening from the stomach, leakage at the connection between the stomach and intestine, and pneumonia and blood clots. The incidence of gallstones and subsequent gallbladder removal is high because of the rapid weight loss that occurs following surgery. The complication rate is high not only because anesthesia and surgery are risky in individuals who are obese, but also because only a limited number of surgeons and surgical centers have experience with these procedures.

In addition to surgical complications, long-term issues can arise that affect digestion and lifestyle. Procedures that reduce the length of the small intestine reduce nutrient absorption and can lead to deficiencies of vitamin B_{12}, folate, calcium, and iron if dietary supplements are not consumed for life. Some people feel very sleepy after eating, and many experience chronic diarrhea, gas, foul-smelling stools, and other changes in bowel habits. People who have this surgery must be willing to commit to changes in the types and amounts of food they consume. Eating too much or eating the wrong foods may induce vomiting or cause food to dump rapidly into the small intestine, leading to symptoms such as nausea, rapid pulse, and diarrhea. In addition, changes in body size and eating habits have emotional consequences that contribute to a post–bariatric surgery divorce rate that is higher than the national average.[93]



Nick Elgar/Getty Images News and Sport Services

Gregory Pace/©Corbis

Significant weight loss is usually achieved 18 to 24 months after weight-loss surgery. NBC's *Today* show weather anchor Al Roker lost 100 lb after undergoing gastric bypass surgery.

So is bariatric surgery a good option? It is expensive and risky, but results are impressive in the first decade after the procedures. For those who have high blood pressure, diabetes, high blood cholesterol, and arthritis, all of which are helped by weight loss, the surgery can enhance quality of life and even be lifesaving. But we still do not understand what the consequences of rearranging the GI anatomy will be in 20 or 30 years.

THINK CRITICALLY: In patients who have undergone bariatric surgery, some weight gain is common after two to five years. Why might this weight gain occur?

BMI $\geq$ 35 kg/m^2 with one or more obesity-related risk factors and who have failed to lose sufficient weight to improve their health using lifestyle interventions.[64] Whether surgery is recommended needs to be evaluated on an individual basis to assess the potential risks and benefits of the surgery. To be successful, the individual must understand the procedure and its risks and be aware of how his or her life may change after the operation. Even after surgery, success requires a lifelong behavioral commitment that includes well-balanced eating and physical activity (see **Debate: Is Surgery a Good Solution to Obesity?**).

adjustable gastric banding A surgical procedure to treat obesity in which an adjustable band is placed around the upper portion of the stomach in order to limit the volume that the stomach can hold and the rate of stomach emptying.

gastric sleeve surgery A surgical procedure to treat obesity that involves removing a large part of the stomach so the remainder resembles a tube or sleeve in order to limit the volume that the stomach can hold.

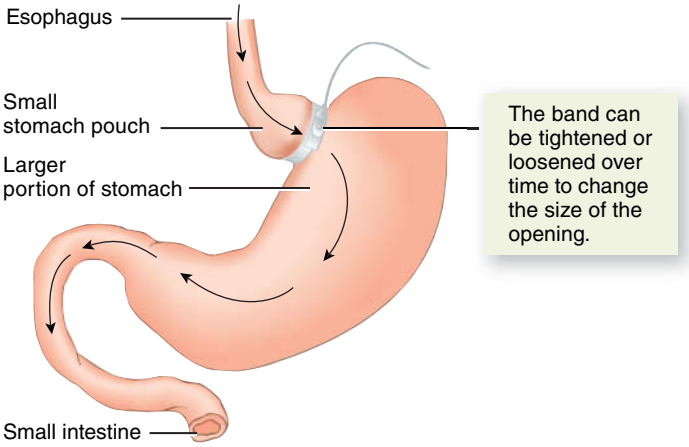
How Gastric Banding and Gastric Sleeve Surgery Promote Weight Loss

Adjustable gastric banding and **gastric sleeve surgery** are procedures that just restrict the amount of food that can be consumed. Gastric banding uses an adjustable band to create a small pouch at the upper end of the stomach (Figure 7.31A). This new, smaller stomach, which typically holds about 1 oz, limits the amount of food that can be comfortably consumed at one time and slows the rate at which food leaves the stomach. Gastric sleeve surgery removes about 70% to 80% of the stomach so that it takes the shape of a tube or sleeve (Figure 7.31B). The size of the stomach is reduced and thus restricts the amount of food that can be consumed. It has been found to be more effective for weight loss than gastric banding.[92] Both these procedures can be done laparoscopically, through a series of small incisions, so that recovery time is kept to a minimum. They also both leave intact the pyloric sphincter, which regulates stomach emptying, so there are fewer complications.

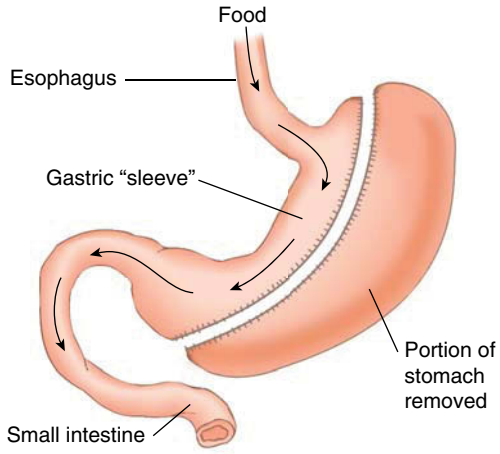
How Gastric Bypass Promotes Weight Loss

Gastric bypass causes a reduction in both food intake and nutrient absorption by bypassing part of the stomach and small intestine. The procedure bypasses the lower portion of the stomach and connects the small stomach pouch to a portion of the small intestine. The smaller stomach limits intake, and the shorter intestine reduces absorption (Figure 7.31C). Individuals who have this procedure, or any bariatric surgery, must

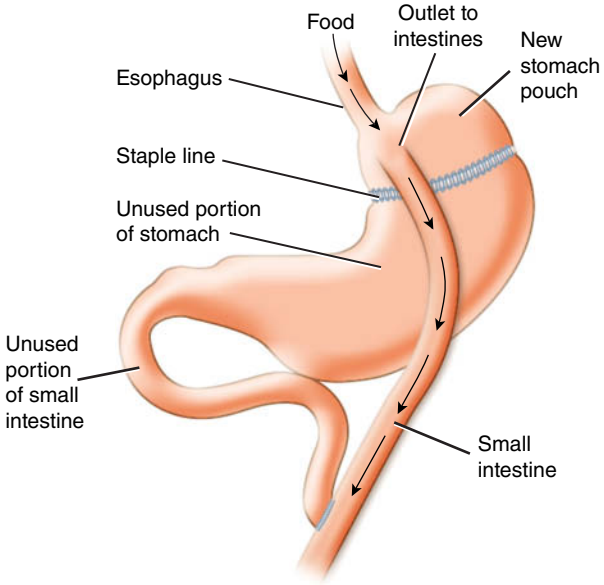
FIGURE 7.31 Types of bariatric surgery



A. Gastric banding involves surgically placing an adjustable band around the upper part of the stomach, creating a small pouch. Gastric banding entails less surgical risk and is more easily reversible than other types of weight-loss surgery.



B. Gastric sleeve surgery involves surgically removing a large part of the stomach. The procedure is not reversible and since it is relatively new, the long-term risks and effectiveness are not known.



C. Gastric bypass surgery bypasses most of the stomach. The procedure illustrated here is the Roux-en-Y gastric bypass, which creates a stomach pouch about the size of an egg and connects it to the jejunum.

make permanent changes in their eating habits and experience permanent changes in their bowel habits. Gastric bypass is more effective for weight loss but is associated with more complications than gastric banding or gastric sleeve surgery.[92]

gastric bypass A surgical procedure to treat morbid obesity that both reduces the size of the stomach and bypasses a portion of the small intestine.

Does Liposuction Cause Weight Loss? **Liposuction** is another surgical procedure for reducing body fat, but it is primarily a cosmetic one. It involves inserting a large hollow needle under the skin into a localized fat deposit and literally vacuuming out the fat. It is often advertised as a way to remove cellulite, which is just fat that has a lumpy appearance because of the presence of connections to the tissue layers below. The risks of liposuction include those associated with general anesthesia and the possibility of infection. The procedure can reduce the amount of fat in a specific location, but will not significantly reduce overall body weight. Liposuction has not been found to affect obesity-related metabolic abnormalities; therefore, unlike overall weight loss, it does not reduce the risk of heart disease and diabetes that is associated with excess body fat.[96]

liposuction A procedure that suctions out adipose tissue from under the skin; used to decrease the size of local fat deposits such as on the abdomen or hips.

OUTCOME

Exactostock/SuperStock

When Bethany got back to school, she enrolled in a nutrition class for the following semester. The class taught her that weight loss is not about going on a diet. She found out that her Bermuda diet worked because limiting her food choices limited her calorie intake but it was not something she could do for life. Weight management is about developing a lifestyle that shifts energy balance to maintain or lose weight. Now instead of having fruit one day and vegetables the next, Bethany makes half her plate fruits and vegetables and fills the other half with whole grains and lean protein foods, and drinks water or low-fat milk instead of soda. She can't eat all she wants, but because she is making nutrient-dense choices by avoiding foods with lots of unhealthy fats or added sugar, she can eat enough volume to feel full. With these changes, she is happy to see that she is slowly losing weight at a rate of about a half a pound per week. **When she reaches her goal weight, she does not plan to make any changes in her diet other than to add enough calories to prevent further weight loss.**

SUMMARY

7.1 Body Weight and Health

- The rapid rise in the incidence of overweight and obesity in the United States during the past 50 years has been called an epidemic. It is also a growing problem around the world.
- More Americans are obese today because, as a population, we are taking in more calories and expending fewer. We eat more today because we are exposed to large portions of a wide variety of tasty, convenient foods that stimulate our appetite. We move less due to modern conveniences, busy lifestyles, and the availability of sedentary ways to spend our leisure time.
- Some body fat is essential for health, but too much increases the risk of developing chronic conditions, such as diabetes, cardiovascular disease, high blood pressure, and abnormal blood lipids, that are part of the metabolic syndrome, as well as gallbladder disease, sleep apnea, arthritis, and certain types of cancer. Excess body fat also creates psychological and social problems.
- Being naturally lean decreases health risks, but if low body weight is due to starvation or eating disorders, it can affect electrolyte balance and immune function and increase the risk of early death.

7.2 Guidelines for a Healthy Body Weight

- A healthy body weight is a weight at which the risks of illness and death are lowest. These risks are associated not only with body weight but also with the amount and location of body fat. The most common way to evaluate the healthfulness of body weight is body mass index (BMI), which is calculated from a ratio of weight to height squared. In general, people with a BMI of 18.5 to 24.9 kg/m^2 have the lowest health risks.
- Assessment of a healthy body weight must consider body composition and the location of body fat. The amount of body fat can be assessed using techniques such as bioelectric impedance, skinfold thickness, underwater weighing, air displacement, dual-energy X-ray absorptiometry, and isotope dilution techniques.
- An increase in visceral fat is associated with a greater incidence of cardiovascular disease, high blood pressure, stroke, diabetes, certain types of cancer, and sleep apnea than an increase in subcutaneous fat. Waist measurement can be used to assess the presence of too much visceral fat.

7.3 Exploring Energy Balance

- The principle of energy balance states that if energy intake equals energy needs, body weight will remain constant. Energy is provided to the body by the carbohydrate (4 kcal/g), fat (9 kcal/g), protein (4 kcal/g), and alcohol (7 kcal/g) in food and beverages. To power the body, these need to be broken down and their energy converted into ATP. The ATP then fuels metabolic reactions that build and maintain body components and provide energy for other cellular and body activities.
- Total energy expenditure (TEE) includes the energy required for basal metabolism, physical activity, the thermic effect of food, growth, milk production in lactating women, and maintenance of body temperature in a cold environment. The largest component of energy expenditure in most people is basal energy expenditure (BEE), which varies depending on body size, body composition, age, and gender. The energy needed for activity, which includes planned exercise and nonexercise activity thermogenesis (NEAT), typically accounts for 15 to 30% of energy expenditure but varies greatly depending on the individual. The thermic effect of food (TEF) is the energy required for the digestion of food and the absorption, metabolism, and storage of nutrients. It is equal to about 10% of energy consumed.
- When the diet contains more calories than are needed, the extra energy is stored for later use, primarily as fat. When the diet does not meet needs, body stores are used. Glucose is provided by the breakdown of glycogen stores or synthesized from amino acids by gluconeogenesis. Energy for tissues that don't require glucose is provided by the breakdown of stored fat.

7.4 Estimating Energy Requirements

- The amount of energy expended by the body can be determined by direct calorimetry, which measures the heat produced by the body, and indirect calorimetry, which measures oxygen utilization. The doubly labeled water method estimates energy expenditure by using water labeled with isotopes of hydrogen and oxygen to calculate carbon dioxide production. Current recommendations for energy needs were determined using the doubly labeled water method.
- Energy needs can be predicted by calculating Estimated Energy Requirements (EERs). EER calculations take into account age, gender, life stage, height, weight, and activity level. As physical activity increases, more calories need to be consumed to maintain body weight.

7.5 What Determines Body Size and Shape?

- The genes people inherit determine their body shape and characteristics. Genes involved in regulating body fatness are referred to as obesity genes. Body weight is determined by the balance between the genes a person inherits and the lifestyle choices he or she makes.
- Signals from the GI tract, hormones, and levels of circulating nutrients regulate body weight in the short term by affecting hunger and satiety. Signals that relay information about the size of body fat stores, such as the release of leptin from adipocytes, regulate long-term energy intake and expenditure. Although body weight appears to be regulated around a set point, these regulatory mechanisms are much better at preventing weight loss than at defending against weight gain.
- The genes people inherit interact with one another and affect metabolic rate, food intake, fat storage, and activity level. Inheriting a thrifty metabolism and having less ability to respond to an increase in calorie intake by dissipating the excess energy in metabolism or NEAT expenditure have been hypothesized to contribute to obesity.

7.6 Weight Management

- Whether individuals need to lose weight depends on how much body fat they have, where the fat is located, and what their health risks are.
- A slow, steady weight loss of 0.5 to 2 lb/week with a goal of reducing weight by 5 to 10% in six months is recommended. To lose a pound of adipose tissue, expenditure must exceed intake by approximately 3500 kcal.
- Weight loss causes a reduction in basal metabolic rate and a decrease in the amount of energy expended in activity. This contributes to the high rate of weight regain.
- Weight management involves adjusting energy intake and expenditure and modifying long-term behaviors. The program that is most effective for weight loss depends on the individual.
- To reduce the incidence of obesity, Americans need to move more and eat less. This will require the involvement of food manufacturers, restaurants, schools, businesses, and communities. Even a shift in energy balance of 100 kcal a day would prevent further weight gain in most people.
- If underweight is not due to a medical condition, weight gain can be accomplished by increasing energy intake and lifting weights to increase muscle mass.

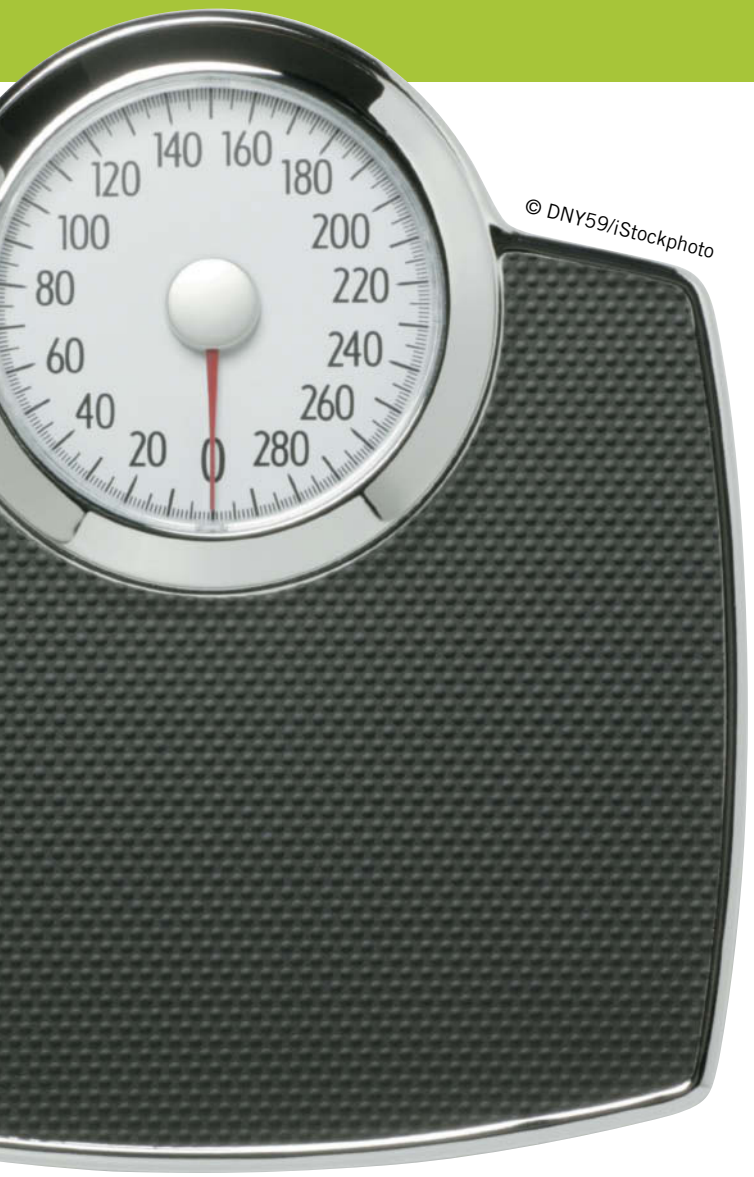
7.7 Approaches to Weight Loss

- There are thousands of diets that promise weight loss. All cause short-term weight loss because they decrease energy intake. Common methods for reducing calorie intake include the use of food groups, prepackaged meals and formulas, and altering the macronutrient distribution of the diet. A good weight-loss diet is one that allows a wide range of food choices, does not require the purchase and consumption of special foods or combinations of foods, and can be followed for life.

Go to WileyPLUS to view a video clip on evaluating diets.

- Prescription weight-loss drugs are recommended only for individuals who are significantly overweight or have accompanying health risks. Those currently available act by suppressing appetite or blocking fat absorption. Non-prescription weight-loss medications and dietary supplements are also available. Some herbal weight-loss supplements may cause serious side effects.
- Weight-loss surgery is a drastic measure that is considered only for those whose health is seriously at risk because of their obesity. Common procedures include adjustable gastric banding, gastric sleeve surgery, and gastric bypass. These surgeries cause changes in the GI tract that affect the amount of food that can be consumed and the absorption of nutrients. Even after surgery, weight loss requires changes in eating patterns and behavior.

FOCUS ON Eating Disorders



© DNY59/iStockphoto

CHAPTER OUTLINE

FOCUS 2.1 **What Are Eating Disorders?**

FOCUS 2.2 **What Causes Eating Disorders?**

The Role of Genetics

Psychological Characteristics

Sociocultural Factors

FOCUS 2.3 **Anorexia Nervosa**

Psychological Issues

Behaviors Associated with Anorexia Nervosa

Physical Symptoms of Anorexia Nervosa

Treatment

FOCUS 2.4 **Bulimia Nervosa**

Psychological Issues

Behaviors Associated with Bulimia Nervosa

Physical Complications of Bulimia Nervosa

Treatment

FOCUS 2.5 **Binge-Eating Disorder**

FOCUS 2.6 **Eating Disorders in Special Groups**

Eating Disorders in Men

Eating Disorders During Pregnancy

Eating Disorders in Children

Eating Disorders in Athletes

Eating Disorders and Diabetes

FOCUS 2.7 **Preventing and Getting Treatment for Eating Disorders**

How to Recognize Those at Risk

How to Get Help for a Friend or Family Member

Reducing the Prevalence of Eating Disorders

Normal eating patterns are flexible. One day you may eat twice as much as on another. On some days your food choices are varied and nutritious, while on others you may survive on snacks and fast food. Lunch one day may include an appetizer, entree, and dessert, and on the next it may be a carton of yogurt grabbed on the run. Normal eating patterns include eating more than we need at a party or other special occasion and less than we need when we are busy or stressed. Normal eating may also involve limiting intake in order to manage weight and meet recommendations for a healthy diet. What and how much people eat vary in response to

social occasions, emotions, time limitations, hunger, and the availability of food, but generally people eat when they are hungry, choose foods they enjoy, and stop eating when they are satisfied. Abnormal eating occurs when a person is overly concerned with food, eating, and body size and shape. **When the emotional aspects of food and eating overpower the role of food as nourishment an eating disorder may develop.**

F2.1 What Are Eating Disorders?

LEARNING OBJECTIVES

- Define eating disorder.
- Distinguish among anorexia nervosa, bulimia nervosa, and binge-eating disorder.
- Explain what is meant by the binge/purge cycle.

Eating disorders are psychological disorders. They involve a persistent disturbance in eating or eating-related behavior that results in altered consumption or absorption of food severe enough to impair physical and nutritional health and psychosocial functioning.[1] If untreated, some eating disorders can be fatal. Mental health guidelines define a number of eating disorders including **anorexia nervosa**, **bulimia nervosa**, and **binge-eating disorder**. Table F2.1 summarizes characteristics that can be used to distinguish these.

eating disorder A persistent disturbance in eating behavior or other behaviors intended to control weight that affects physical health and psychosocial functioning.

anorexia nervosa An eating disorder characterized by self-starvation, a distorted body image, and below-normal body weight.

bulimia nervosa An eating disorder characterized by the consumption of large amounts of food at one time (binge eating), followed by purging behaviors such as vomiting or the use of laxatives to eliminate calories from the body.

binge-eating disorder An eating disorder characterized by recurrent episodes of binge eating in the absence of purging behavior.

TABLE F2.1 Distinguishing among Eating Disorders

Characteristic	Eating disorder		
	Anorexia nervosa	Bulimia nervosa	Binge-eating disorder
Body weight	Below normal	Normal or overweight	Above normal
Binge eating	Possibly	Yes, at least once a week for three months	Yes, at least once a week for three or more months
Purging	Possibly	Yes, at least once a week for three months	No
Restricts food intake	Yes	Yes	Yes
Body image	Dissatisfaction with body and distorted image of body size	Dissatisfaction with body and distorted image of body size	Dissatisfaction with body
Fear of being fat	Yes	Yes	Not excessive
Self-esteem	Low	Low	Low
Typical age of onset	Adolescence/young adulthood	Adolescence/young adulthood	Adolescence and any age during adulthood

F2.2 What Causes Eating Disorders?

LEARNING OBJECTIVES

- Describe the genetic, psychological, and sociocultural factors that influence the development of eating disorders.
- Discuss how body ideal and the media affect the incidence of eating disorders.

We do not completely understand what causes eating disorders, but we do know that genetic, psychological, and sociocultural factors contribute to their development (Figure F2.1). Eating disorders can be triggered by traumatic events such as sexual abuse or by day-to-day occurrences

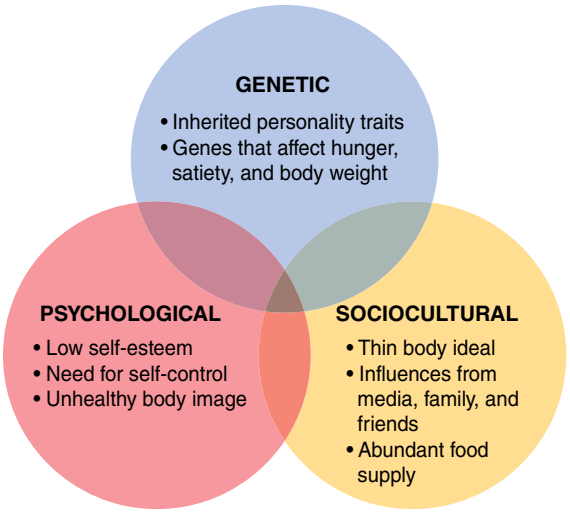


FIGURE F2.1 Causes of eating disorders
Genetic, psychological, and sociocultural factors contribute to the development and persistence of eating disorders.

such as teasing or judgmental comments by a friend or a coach. Eating disorders occur in both genders and in people of all ages, races, and socioeconomic backgrounds, but some groups are at greater risk than others.[2] Women are more likely than men to develop eating disorders. Professional dancers, models, certain types of athletes, and others who are concerned about maintaining a low body weight are most likely to develop eating disorders. Eating disorders commonly begin in adolescence, when physical, psychological, and social development is occurring rapidly.

The Role of Genetics

Both genetic and environmental factors contribute to the development of eating disorders. Although specific genes linked to eating disorders have not yet been identified, studies of twins have shown that a significant portion of the risk of developing anorexia and bulimia is inherited.[3] Binge-eating disorder is seen in some people with a defect in a gene called the melanocortin-4 receptor gene. The protein made by this gene helps control hunger and satiety. If this gene is abnormal and makes too little protein, the person feels too much hunger. This genetic defect has been linked to obesity, but not consistently to binge-eating disorder.[4]

Inheritance of certain personality traits and other biological characteristics might also predispose individuals to developing an eating disorder. For example, inherited abnormalities in the function of the neurotransmitter serotonin, which affects food intake and mood, have been hypothesized to contribute to the behaviors typical of anorexia and bulimia.[5] Eating disorders are complex diseases that are most likely the result of the interaction of multiple genes with the environment. When placed in an environment conducive to eating disorders, individuals with a genetic predisposition will be more likely to develop one.

Psychological Characteristics

self-esteem The general attitude of approval or disapproval that people have about themselves.

Certain personality traits and psychological problems are common among individuals with eating disorders.[6] For example, people with eating disorders often have low **self-esteem**. Self-esteem refers to the judgments people make and maintain about themselves—a general attitude of approval or disapproval that indicates if the people think they are worthy and capable. Eating disorders are also rooted in the need for self-control. Those with eating disorders are often perfectionists who set very high standards for themselves and others. In order to be perfect, they strive to be in control of their bodies and their lives. They view everything as either a success or a failure. Being fat is seen as failure, thin as success, and thinner as even more successful. In spite of their many achievements, those with eating disorders feel inadequate, defective, and worthless.

People with eating disorders often try to use their relationship with food to gain control over their lives and boost their self-esteem. They believe that controlling their food intake and weight demonstrates their ability to control other aspects of their lives and solve other problems. Their fixation with food and weight loss and their ability to control their intake and weight help them to feel better about themselves. Even if they feel insecure, helpless, or dissatisfied in other aspects of life, if they are in control of their food intake, weight, and body size, they can associate this control with success. This feeling of being in control can become addictive.

Sociocultural Factors

While genetic and psychological traits may predispose individuals to eating disorders, sociocultural factors are important environmental triggers for the onset of these disorders. One important sociocultural factor is body ideal. What is viewed as an ideal body differs across cultures and

has changed throughout history. Ancient drawings and figurines show women with large breasts and swollen abdomens. This plump body ideal is still prevalent today in cultures where food is not readily available. Young women in these cultures may struggle to gain weight to achieve what is viewed as the ideal female body. As these cultures are exposed to Western media, body ideal is changing (Figure F2.2). Women in the United States today strive to achieve a thin, lean body. The sociocultural ideals about body size are linked to **body image** and the incidence of eating disorders.[7] Eating disorders occur in societies where food is abundant and the body ideal is thin. They are rare where food is scarce and people must worry about where their next meal is coming from.

© Michael DeFreitas Pacific/ Alamy

FIGURE F2.2 Fiji's changing body ideal
"You've gained weight" had been a traditional compliment in the South Pacific nation of Fiji, where a fuller figure is traditionally desirable. But as young Fijians are influenced by Western cultures where thin is in, young women have become more preoccupied or dissatisfied with their body weight and shape, and some have begun using purging behavior to their control weight.[8]

Body Ideal in Modern America From television and movies to magazines and advertisements and even toys, the culture in the United States today is a culture of thinness (Figure F2.3). Messages about what society views as a perfect body—the ideal we should strive for—are constantly delivered by the mass media. The perfect body is long, lean, and muscled. The tall dark muscular man gets the girl; the thin athletic woman gets her man. Thin fashion models adorn billboards and magazine covers to show off the latest clothes.

body image The way a person perceives and imagines his or her body.

Being thin is associated with beauty, success, intelligence, and vitality. Being plump, on the other hand, is associated with failure, stupidity, and clumsiness. What young woman would want to be plump when exposed to these negative associations? Although men are also affected by these messages, American culture still places much more emphasis on the appearance of women's bodies. A young woman facing a future where she must be independent, have a prestigious job, maintain a successful love relationship, bear and nurture children, manage a household, and stay in fashion can become overwhelmed. Unable to master all these roles, she may look for some aspect of her life that she can control. Food intake and body weight are natural choices, since being thin brings the societal associations of success. These messages about how we should look are difficult to ignore and can create pressure to achieve this ideal body. But it is a standard that is very hard to meet—a standard that is contributing to disturbances in body image and eating behavior. This is illustrated by the fact that, as the body dimensions of

FIGURE F2.3 Body ideal in the United States

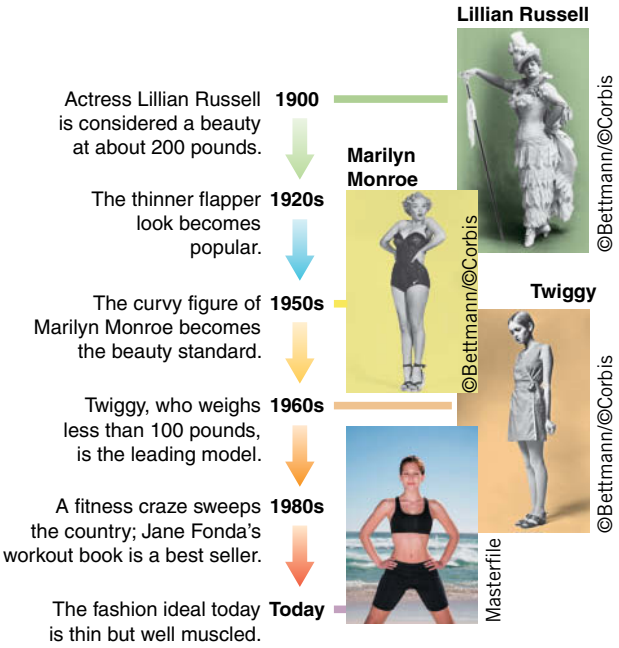
© Oa Chonhatai / Alamy

A. The toys that children play with set a cultural standard for body ideal. Little girls playing with Barbie dolls want to be like Barbie when they grow up, and boys playing with Superman, Batman, or GI Joe action figures want to be like them. This includes looking like them. Unfortunately, Barbie's measurements would be virtually unachievable if Barbie were life-sized. The same is true of the big chest, muscular arms and legs, and flat stomach with "six-pack" abs seen on male action figures.

Andy Washnik

B. Magazine covers and advertisements emphasize thinness as a standard for female beauty. These "ideal" bodies are frequently atypical of normal, healthy women.

FIGURE F2.4 The changing female body ideal
Thinness has not always been the beauty standard in the United States. This time line shows how the female body ideal has changed over the years.



female models, actresses, and other cultural icons have become thinner during the past several decades, the incidence of eating disorders has increased (Figure F2.4).

Body Image and Eating Disorders What individuals think they should look like or wish they looked like is affected by the ideals of their culture and society. Many women and girls, particularly teenage girls, are dissatisfied with their bodies because they look different from what they and their culture see as ideal. In the United States today, fashion models weigh 23% less than the average female. Although many women strive for this thin ideal, only 1% of young women have a chance of being as thin as a supermodel.[9] Almost everyone has some degree of body dissatisfaction, something that they would like to change about their bodies. For some, however, this becomes a pathological concern with body weight and shape, and as a result, body image may become distorted. A distorted body image means that individuals are unable to judge the size of their own body and do not see themselves as they really are. Body image distortion is common with eating disorders, so even if these individuals achieve a body weight comparable to that of a fashion model, they may continue to see themselves as fat and strive to lose more weight (Table F2.2).

TABLE F2.2 To Maintain a Healthy Body Image

Try to . . .
• Accept that healthy bodies come in many shapes and sizes.
• Recognize your positive qualities.
• Remember that you can be your worst critic.
• Explore your internal self, as well as your external appearance.
• Spend your time and energy enjoying the positive things in your life.
• Be aware of your own weight prejudice. Explore how your feelings may affect your self-esteem.
And try not to . . .
• Let your body define who or what you are.
• Judge others on the basis of appearance, body size, or shape.
• Forget that society changes its ideals of beauty over the years.
• Forget that you are not alone in your pursuit of self-acceptance.
• Be afraid to enjoy life.

F2.3 Anorexia Nervosa

LEARNING OBJECTIVES

- Describe the physical and psychological features of anorexia nervosa.
- Discuss the health consequences of anorexia.
- Explain how anorexia is treated.

Anorexia means lack of appetite, but in the case of the eating disorder anorexia nervosa, it is a desire to be thin, rather than a lack of appetite, that causes individuals to decrease their food intake. Anorexia nervosa was first recognized by physicians in the second half of the 19th century. Today it is diagnosed based on three characteristics: restriction of energy intake, intense fear of gaining weight, and a distorted body image (Table F2.3).[1] It most commonly begins during adolescence or young adulthood with peak onset between 13 and 18 years of age. The

TABLE F2.3 Diagnostic Criteria for Anorexia Nervosa[1]

- Restriction of energy intake relative to requirements, leading to a significantly low body weight. *Significantly low weight* is defined as a weight that is less than minimally normal or, for children and adolescents, less than that minimally expected.
- Intense fear of gaining weight or of becoming fat, or persistent behavior that interferes with weight gain, even though at a significantly low weight.
- Disturbance in the way in which one's body weight or shape is experienced, undue influence of body weight or shape on self-evaluation, or persistent lack of recognition of the seriousness of the current low body weight.

Restricting Type: Weight loss is accomplished by restricting food intake and/or exercising excessively; during the previous three months, the individual has not engaged in recurrent episodes of binge eating or purging behavior.

Binge-Eating or **Purging Type:** Restricts food intake and, during the previous three months, the individual has engaged in recurrent episodes of binge eating or purging behavior.

prevalence is estimated to be as high as 4% of the female population.[10,11] The death rate is about 5 deaths per 1000 persons per year, and 1 in 5 of those who die commit suicide.[12]

Psychological Issues

The psychological component of anorexia nervosa revolves around an overwhelming fear of gaining weight, even in those who are already underweight. It is not uncommon for individuals with anorexia to feel that they would rather be dead than fat. Anorexia is also characterized by disturbances in body image or perception of body size that prevent those affected from seeing themselves as underweight even when they are dangerously thin (Figure F2.5). Those with this disorder may use body weight and shape as a means of self-evaluation: "If I weren't so fat then everyone would like and respect me and I wouldn't have other problems." However, no matter how much weight they lose, individuals with anorexia nervosa do not gain self-respect, inner assurance, or the happiness they seek. Therefore, they continue to restrict their food intake to promote weight loss.

© Ted Foxx/Alamy Limited

FIGURE F2.5 Distorted body image
When people with a distorted body image look in the mirror they see themselves as fat even when they are at a healthy weight or underweight.

Behaviors Associated with Anorexia Nervosa

The most obvious behaviors associated with anorexia are those that contribute to the maintenance of a low body weight (Figure F2.6). These behaviors include restriction of food intake, binge-eating and purging episodes, strange eating rituals, and excessive exercise.

© Aldo Murillo/iStockphoto

Dear Diary,

For breakfast today I had a cup of tea. For lunch I ate some lettuce and a slice of tomato, but no dressing. I cooked dinner for my family. I love to cook, but it is hard not to taste. I tried a new chicken recipe and served it with rice and asparagus. I even made a chocolate cake for dessert but I didn't even lick the bowl from the frosting. When it came time to eat, I only took a little. I told my mom I nibbled while cooking. I pushed the food around on my plate so no one would notice that I only ate a few bites. I was good today - I kept my food intake under control. The scale says I have lost 20 pounds but I still look fat.

FIGURE F2.6 A day in the life of a person with anorexia
People with anorexia nervosa carefully regulate what they eat to maintain a very low body weight.

Peopleimages / Getty Images, Inc.

FIGURE F2.7 Anorexia and exercise
People with anorexia nervosa often use exercise as well as food restriction to achieve and maintain a very low body weight.

Based on these behaviors, anorexia is subdivided into two subtypes. Those with the *Restricting Type* maintain their low body weight solely by restricting their food intake and increasing their activity. Those with the *Binge-Eating* or *Purging Type* also typically restrict their food intake but, in addition, regularly engage in **binge eating** and/or **purging** behaviors (see Table F2.3). It is estimated that about half of people with anorexia use purging as a means of weight control.[13]

For individuals with anorexia, food and eating become an obsession. In addition to restricting the total amount of food consumed, people with anorexia develop personal diet rituals, limiting certain foods and eating them in specific ways. Although they do not consume very much food, they are preoccupied with food and spend an enormous amount of time thinking about food, talking about food, and preparing food for others. Instead of eating, they move the food around the plate and cut it into tiny pieces (see Figure F2.6).

Both hyperactivity and overactivity are behaviors that are also typical of anorexia. This is in contrast to the decrease in activity and fatigue characteristic of other starvation states associated with weight loss. Many people with anorexia exercise excessively to burn calories. For some, the activity is surreptitious, such as going up and down stairs repeatedly or getting off the bus a few stops early. For others, the activity takes the form of strenuous physical exercise. They may become fanatical athletes and feel guilty if they cannot exercise. The exercise is typically done alone and is performed as a regular rigid routine. They may link exercise and eating, so a certain amount of exercise earns them the right to eat and if they eat too much they must pay the price by adding extra exercise. Those who use exercise to increase energy expenditure do not stop when they are tired; instead, they train compulsively beyond reasonable endurance (Figure F2.7).

binge eating The rapid consumption of a large amount of food in a discrete period of time associated with a feeling that eating is out of control.

purging Behaviors such as self-induced vomiting and misuse of laxatives, diuretics, or enemas to rid the body of calories.

Physical Symptoms of Anorexia Nervosa

The first obvious physical manifestation of anorexia is a significantly low body weight. For adults, a BMI of less than 17 kg/m^2 may be used as a criterion. In children and adolescents, age, growth, and stage of development must be taken into consideration when evaluating weight.[1]

Restriction of energy and nutrient intake affects most organ systems. As weight loss becomes severe, symptoms of starvation begin to appear. Starvation affects brain function, causing those with anorexia to become apathetic, dull, exhausted, and depressed. Physical symptoms include depletion of fat stores; wasting of muscles; inflammation and swelling of the lips; flaking and peeling of skin; and growth of fine hair, called *lanugo hair,* on the body, and dry, thin, brittle hair on the head that may fall out. In adult females, estrogen levels drop and menstruation may become irregular or stop, a condition called **amenorrhea**. In children and adolescents, low estrogen can delay sexual maturation and can have long-term effects on bone density. Bone density can also be negatively affected by low lean body mass, low calcium intake, low vitamin D levels, low impact force with exercise, and alterations in other hormones that affect bone metabolism.[2] In males with anorexia, testosterone levels decrease, contributing to low bone density.[14]

amenorrhea Delayed onset of menstruation or absence of three or more consecutive menstrual cycles.

In the final stages of starvation, electrolyte and fluid balance abnormalities and cardiac irregularities occur. Ketones are typically absent because fat stores are depleted. Immune function is suppressed, leading to infections, which further increase nutritional needs.

Treatment

The goal of treatment for anorexia nervosa is to restore body weight and medical and nutritional health and to resolve the psychological and behavioral problems.[2] Treatment requires an interdisciplinary team of nutritional, mental health, and medical specialists.[15] Early treatment of anorexia is important because starvation may cause irreversible damage. The goal of nutrition intervention is to promote weight gain by increasing energy intake and expanding dietary choices.[15] In most cases outpatient treatment is possible. In more severe cases, hospitalization is required so food intake and exercise behaviors can be carefully controlled. Intravenous nutrition may be necessary to keep these individuals alive.

Psychological therapy focuses not on what caused the problem, but on restoring health and control over eating. Family-based treatment has been found to be most effective.[2] Treatment of children and adolescents involves parents in all three phases of treatment: restoring the child's weight to a healthy level, returning control over eating to the child or adolescent, and finally establishing a healthy adolescent identity.[16] Recovery typically requires years of therapy. Although some people recover fully from anorexia, others have poor long-term outcomes—remaining irrationally concerned about weight gain and never achieving normal body weight.

F2.4 Bulimia Nervosa

LEARNING OBJECTIVES

- Describe the physical and psychological features of bulimia nervosa.
- Discuss the health consequences of bulimia.
- Explain how bulimia is treated.

Bulimia is from the Greek *bous* (ox) and *limos* (hunger), denoting hunger of such intensity that a person could eat an entire ox. The modern concept of bulimia nervosa as an eating disorder arose in the early 1970s, when a set of symptoms was identified and distinguished from anorexia and obesity. Many different names were used for this disorder, including dysorexia, bulimarexia, thin-fat syndrome, binge/purge syndrome, and dietary chaos syndrome. The term *bulimia nervosa* was coined in 1979 by a British psychiatrist who suggested that bulimia consisted of powerful urges to overeat in combination with a morbid fear of becoming fat and the avoidance of the fattening effects of food by inducing vomiting or abusing purgatives or both.[17] Today, the estimated lifetime prevalence for bulimia nervosa for women is about 2%.[10] It commonly begins in adolescence or young adulthood. A diagnosis of bulimia is based on the presence of recurrent episodes of binge eating, inappropriate compensatory behaviors to prevent weight gain, and self-evaluation that is unduly affected by body shape and weight (Table F2.4).[1]

Psychological Issues

As with anorexia, people with bulimia have an intense fear of becoming fat. They have a negative body image accompanied by a distorted perception of their body size. Since their self-esteem is highly tied to their impressions of their body shape and weight, they blame all of their problems on their appearance; this allows them not to face the real problems in their life. People with bulimia are preoccupied with the fear that once they start eating they will not be able to stop. They may engage in continuous dieting, which leads to a preoccupation with food. They also think they are the only person in the world with this problem. As a result, they are often socially isolated. In addition, they may avoid situations that will expose them to food, such as going to parties or out to dinner, further isolating themselves.

TABLE F2.4 Diagnostic Criteria for Bulimia Nervosa[1]

• Recurrent episodes of binge eating. An episode of binge eating is characterized by both of the following:
• Eating, in a discrete period of time (e.g., within any two-hour period), an amount of food that is definitely larger than what most individuals would eat in a similar period of time under similar circumstances.
• A sense of lack of control over eating during the episode (e.g., a feeling that one cannot stop eating or control what or how much one is eating).
• Recurrent inappropriate compensatory behavior to prevent weight gain, such as self-induced vomiting; misuse of laxatives, diuretics, or other medications; fasting; or excessive exercise.
• The binge eating and inappropriate compensatory behaviors both occur, on average, at least once a week for three months.
• An overemphasis on the importance of body shape and weight on self-evaluation.
• This disturbance does not occur exclusively during episodes of anorexia nervosa.

Behaviors Associated with Bulimia Nervosa

Bulimia typically begins with food restriction motivated by the desire to be thin. Overwhelming hunger may finally cause the dieting to be interrupted by a period of overeating. Eventually a pattern develops involving semi-starvation interrupted by periods of gorging. During a food binge, a person with bulimia experiences a sense of lack of control over their eating behavior. The amount of food consumed during an episode of binge eating varies, but is larger than most people would eat during a similar period of time under similar circumstances. A typical binge includes on the order of 3400 kcal, while a normal teenager may consume 2000 to 3000 kcal in an entire day. One study found that people with bulimia consumed an average of about 7000 kcal in a 24-hour period.[18] Binges usually last less than two hours and occur in secrecy. They stop when the food runs out or when pain, fatigue, or an interruption intervenes (**Figure F2.8**).

After binge episodes, individuals with bulimia use various inappropriate compensatory behaviors to eliminate the extra calories and prevent weight gain. These include self-induced vomiting and misuse of enemas, laxatives, diuretics, or other medications, as well as fasting or excessive exercise (see Table F2.4). Self-induced vomiting is the most common purging behavior. It is used at the end of a binge but also after normal eating to eliminate food before it is absorbed and the energy it provides can cause weight gain. At first, a physical maneuver such as sticking a finger down the throat is needed to induce vomiting, but patients eventually learn to vomit at will. Vomiting does not purge all calories consumed in a binge. After a binge containing 3530 kcal, on average 1209 kcal were retained. Interestingly, after a smaller binge of only 1549 kcal, almost the same amount of energy remained in the stomach, 1128 kcal.[19] Some individuals with bulimia take laxatives to induce diarrhea. Although the patients believe the diarrhea prevents calories from being absorbed, in fact, nutrient absorption is almost complete before food enters the colon, where laxatives have their effect. The weight loss associated with laxative abuse is due to dehydration. Diuretics also cause water loss but via the kidney rather than the GI tract. They do not cause fat loss. Some people with bulimia use a combination of purging behaviors to eliminate excess calories.

Physical Complications of Bulimia Nervosa

Individuals with bulimia are typically of normal body weight or overweight (BMI $\geq$ 18.5 kg/m^2 and $<$ 30 in adults). Amenorrhea and low bone density are present in some females with

Jack Star/Photolink/Getty Images, Inc.

Dear Diary,

Today started well. I stuck to my diet through breakfast, lunch, and dinner, but by 8 PM I was feeling depressed and bored. I thought food would make me feel better. Before I knew it I was at the convenience store buying two pints of ice cream, a large bag of chips, a one pound package of cookies, a half dozen candy bars, and a quart of milk. I told the clerk I was having a party. But it was a party of one. Alone in my dorm room I started by eating the chips, then polished off the cookies and the candy bars, washing them down with milk and finishing with the ice cream. Luckily no one was around so I was able to vomit without anyone hearing. I feel weak and guilty but also relieved that I got rid of all those calories. Tomorrow, I will start a new diet.

FIGURE F2.8 A day in the life of a person with bulimia
Bulimia nervosa is characterized by binge eating followed by behaviors such as self-induced vomiting to eliminate the excess calories. Binge eating and purging are followed by intense feelings of guilt and shame.

bulimia, but are not as significant as with anorexia.[2] It is the purging portion of the binge/purge cycle that is most hazardous to health in bulimia nervosa. Purging by vomiting brings stomach acid into the mouth. Frequent vomiting affects the GI tract by causing tooth decay, sores in the mouth and on the lips, swelling of the jaw and salivary glands, irritation of the throat, inflammation of the esophagus, and changes in stomach capacity and stomach emptying.[15] It also causes broken blood vessels in the face from the force of vomiting, electrolyte imbalance, dehydration, muscle weakness, and menstrual irregularities. Potentially fatal complications such as esophageal tears, stomach rupture, and abnormal heartbeat may occur, but are rare.[1] Laxative and diuretic abuse can also cause dehydration and electrolyte imbalance. Rectal bleeding may occur from laxative overuse.

Treatment

The overall goal of therapy for people with bulimia nervosa is to separate eating from their emotions and from their perceptions of success and to promote eating in response to hunger and satiety. Psychological counseling is needed to address issues related to body image and a sense of lack of control over eating. Nutritional therapy addresses physiological imbalances caused by purging episodes and provides education on nutrient needs and how to meet them. Antidepressant medications may be beneficial in reducing the frequency of binge episodes. Treatment has been found to speed recovery, but long-term follow-up indicates that in many individuals symptoms diminish even without treatment.[1]

F2.5 Binge-Eating Disorder

LEARNING OBJECTIVES

- Distinguish eating behavior in binge-eating disorder from that in anorexia and bulimia.
- Describe the health consequences of binge-eating disorder.

Binge-eating disorder typically begins in adolescence or young adulthood, but can also begin later in adulthood. Unlike anorexia and bulimia, binge-eating disorder is not uncommon in men, who account for about 40% of cases.[20] During a 12-month period, binge-eating disorder affects about 1.6% of women and 0.6% of men.[1] Individuals with binge-eating disorder engage in recurrent episodes of binge eating but do not regularly engage in inappropriate compensatory behaviors such as vomiting, fasting, or excessive exercise (**Table F2.5**). As a result, overweight and obesity are common among people with binge-eating disorder (**Figure F2.9**).

TABLE F2.5 Diagnostic Criteria for Binge-Eating Disorder[1]

• Recurrent episodes of binge eating. An episode is characterized by:
• Eating a larger amount of food than normal during a short period of time (within any two-hour period).
• Lack of control over eating during the binge episode (i.e., the feeling that one cannot stop eating).
• Binge-eating episodes are associated with three or more of the following:
• Eating much more rapidly than normal.
• Eating until feeling uncomfortably full.
• Eating large amounts of food when not physically hungry.
• Eating alone because you are embarrassed by how much you're eating.
• Feeling disgusted, depressed, or guilty after overeating.
• Marked distress regarding binge eating is present.
• Binge eating occurs, on average, at least once a week for three months.
• The binge eating is not associated with the regular use of inappropriate compensatory behavior (purging, excessive exercise, etc.) and does not occur exclusively during the course of bulimia nervosa or anorexia nervosa.

Ken Ross/Getty Images, Inc.

Dear Diary,

I got on the scale today. What a mistake! My weight is up to 250 pounds. I hate myself for being so fat. Just seeing that I gained more weight made me feel ashamed - all I wanted to do was bury my feelings in a box of cookies or a carton of ice cream. Why do I always think the food will help? Once I started eating I couldn't stop. When I finally did I felt even more disgusted, depressed, and guilty. I am always on a diet but it is never long before I lose control and pig out. I know my eating and my weight are not healthy but I just can't seem to stop.

FIGURE F2.9 A day in the life of a person with binge-eating disorder
People with binge-eating disorder often seek help for their weight rather than for their disordered eating pattern. It is estimated that 10 to 15% of people enrolled in commercial weight-loss programs suffer from this disorder.[21]

The major complications of binge-eating disorder are the conditions that accompany obesity, such as diabetes, high blood pressure, high blood cholesterol levels, gallbladder disease, heart disease, and certain types of cancer. The primary emphasis of behavioral therapy for binge-eating disorder is on reducing binge eating, with a secondary focus on weight loss.[15] Treatment also involves counseling to improve body image and self-acceptance, a healthy nutritious diet, and increased exercise to promote weight loss.

F2.6 Eating Disorders in Special Groups

LEARNING OBJECTIVES

- Discuss how eating disorders differ in men and women.
- Describe some eating disorders that occur in pregnant women, children, and athletes.
- Explain why diabetes treatment increases the risk of developing an eating disorder.

Although anorexia and bulimia are most common in women in their teens and 20s, eating disorders occur in both genders and all age groups. They can be a complication in pregnant women and a problem for young children and athletes. They also occur in individuals with diseases that have a nutrition component such as diabetes. Some of the less common eating disorders and other abnormal eating behaviors are listed in Table F2.6.

Eating Disorders in Men

The incidence of anorexia and bulimia is much lower among men than women. One reason for the lower incidence is that the cultural pressure for males to be thin is less intense. Women are encouraged to be thin to attract friends and romantic partners and to be successful at school and work, whereas men are encouraged to be strong and powerful. The male ideal is a V-shaped upper body that is muscular, moderate in weight, and low in body fat. This difference in societal expectations is reflected in the BMI of men and women when they first "feel fat" and begin dieting. Women who develop eating disorders generally feel fat and begin dieting when their BMI is in the healthy range, whereas men who develop eating disorders usually do not start dieting until their BMI is in the overweight range.[22] Men also often develop eating disorders at an older age than women.

TABLE F2.6 Other Eating Disorders and Abnormal Eating Behaviors

Disorder/Behavior	Characteristics	Who Is Affected	Consequences
Anorexia athletica	Engaging in compulsive exercise to lose weight or maintain a very low body weight.	Athletes	Can lead to more serious eating disorders and serious health problems including kidney failure, heart attack, and death.
Avoidant/restrictive food intake disorder	Similar to anorexia nervosa in that the individual avoids eating and experiences weight loss and the physical symptoms of anorexia. However, there is no distorted body image or fear of weight gain.	Infants/children/adults	Weight loss, reduced body fat, malnutrition.
Body dysmorphic disorder	An obsession with a perceived defect in the sufferer's body or appearance.	Affects males and females equally	Increased risk for depression and suicide.
Chewing and spitting	The person puts food in his/her mouth, tastes it, chews it, and then spits it out.	Those with other eating disorders	Since the food is not swallowed, the same symptoms as starvation dieting can result.
Diabulimia (insulin misuse)	Withholding insulin to cause weight loss or prevent weight gain.	People who use insulin to treat diabetes	Uncontrolled blood sugar, which can lead to blindness, kidney disease, heart disease, nerve damage, and amputations.
Female athlete triad	A triad of low energy intake, menstrual abnormalities, and low bone mineral density.	Female athletes in weight-dependent sports	Low estrogen levels, which interfere with calcium balance, eventually causing reductions in bone mass and an increased risk of bone fractures.
Muscle dysmorphia (megarexia or reverse anorexia)	Obsession with being small and underdeveloped. Individuals with this disorder believe their muscles are inadequate even when they have a good muscle mass.	Bodybuilders and avid gym-goers; more common in men than women	Individuals with this disorder are at risk if they take steroids or other muscle-enhancing drugs.
Night-eating syndrome	Most of the day's calories are eaten after the evening meal or at night after awakening from sleep. A similar disorder, in which a person may eat while asleep and have no memory of the events, is called nocturnal sleep-related eating disorder. It is considered a sleep disorder, not an eating disorder.	Adults with obesity and those experiencing stress	Obesity
Orthorexia nervosa	Obsession with eating food considered to be healthy or beneficial. Focus on the quality of the food, not the quantity.	No particular group	Harmful to interpersonal relationships.
Pica	Persistent ingestion of nonfood items such as dirt, clay, paint chips, plaster, chalk, laundry starch, and ashes.	Pregnant women, children, people whose family or ethnic customs include eating certain nonfood substances.	Mineral deficiencies, perforated intestines, intestinal infections.
Rumination disorder	Eating, swallowing, and then regurgitating food back into the mouth where it is chewed and then ejected or reswallowed.	Infants/children/adolescents/adults	Bad breath, indigestion, chapped lips, damage to dental enamel and tissues in the mouth, aspiration of food leading to pneumonia, weight loss and failure to grow (children), electrolyte imbalance, and dehydration.
Selective eating disorder	Eating only a few foods, mostly carbohydrate.	Children	Malnutrition

Jim Cummins/Taxi/Getty Images

FIGURE F2.10 The male body ideal
The ideal male body is as difficult for most men to achieve as the thin athletic ideal is for women.

Although men currently represent a small percentage of those with eating disorders, the numbers seem to be on the rise.[23] It is now estimated that 25% of people with anorexia are males.[24] This is likely due to greater recognition and hence diagnosis in this group as well as increasing pressure to achieve an ideal male body. Advertisements directed at men today are showing more and more exposed skin with a focus on well-defined abdominal and chest muscles (Figure F2.10). Just as the Barbie doll set an unrealistic standard for young women, male action figures, superhero cartoons, and media ideals set a standard that is impossible for young men to achieve. This standard contributes to the development of *muscle dysmorphia*, which is the preoccupation with being muscular and lean (see Table F2.6). It leads to extreme dieting and exercise behavior and an increased risk for anabolic steroid use.

The physical consequences of eating disorders are similar in men and women. Both lose bone, but men are more severely affected by disorders related to bone loss and tend to have lower bone mineral density than women with the same disorder.[25] Rather than amenorrhea, men experience a gradual drop in testosterone levels. This causes a loss of sexual desire. Men with eating disorders have psychiatric conditions that are similar to those affecting women, including mood and personality disorders. Like women, men with eating disorders require professional help in order to recover, and the outcome of treatment is similar in men and women. Men, however, are less likely to seek treatment because they do not want to be perceived as having a "woman's disease."

Eating Disorders During Pregnancy

LIFE CYCLE

Eating disorders are common in women in their 20s, an age when many people choose to start a family. If the eating disorder interrupts the menstrual cycle, it will cause infertility.

Some women with eating disorders are able to conceive. Pregnancy is a stressful and anxious time for any woman. In someone with an eating disorder, the weight gain and change in body shape can worsen or cause a recurrence of the disorder.[26] In other women, symptoms may improve because of their concern for the welfare of the baby. Pregnancy can also make other medical problems related to the eating disorder worse, such as liver, heart, and kidney damage. Pregnant women with anorexia are at increased risk of anemia and their babies are more likely to be premature, small for gestational age, low birth weight, or to die immediately before or after birth. Babies born to women with bulimia have more problems in the birthing process and lower birth weights. Women with binge-eating disorder were more likely to have hypertension and to give birth to large-for-gestational-age babies.[27]

What and how much a woman eats during pregnancy also influences the health of the baby after birth (see Chapter 14). Babies born to women with eating disorders are more likely to be slower to grow and develop, and they may lag behind intellectually and emotionally and remain dependent. They may also have difficulty developing social skills and relationships with other people.[28]

pica A persistent ingestion of nonnutritive, nonfood items.

An eating disorder that is more common in pregnancy is **pica** (see Chapters 12 and 14). This is the persistent ingestion of nonfood substances having little or no nutritional value.[1] Commonly consumed substances include soil, clay, chalk, paint chips, laundry starch, ice and freezer frost, talcum powder, charcoal, and ashes. Pica during pregnancy and at any time is potentially dangerous. The consumption of large amounts of nonfood substances may cause micronutrient deficiencies by reducing the intake of nutrient-dense foods and by interfering with the absorption of certain minerals from food. Substances consumed could also cause intestinal obstruction or perforation and could contain toxins or harmful bacteria. The cause of pica is unknown, but it may occur in pregnant women due to changes in food preferences that occur during pregnancy.

Eating Disorders in Children

LIFE CYCLE

Although the incidence is lower than it is in late adolescence and early adulthood, anorexia and bulimia also occur in children under the age of 13.[11] The prevalence of eating disorders has been increasing in younger children in the United States as they are exposed to our cultural values about food and body weight.[29] More girls than boys are affected, but the proportion of boys is increasing and is greater than the proportion of men in the older age groups.[11]

The implications for growth and development are even greater when eating disorders begin at a younger age.

Eating disorders can be difficult to diagnose in children because most children are finicky eaters at some point in their development. But when being finicky becomes extreme and growth is impaired, an eating disorder may be the cause. Disorders may involve consumption of a very limited number of foods or a general restriction of food intake (see Table F2.6). Younger children with eating disorders may present differently than adolescents. For example, instead of rapid weight loss, they may fail to make expected gains in weight or height, and they may not have body image concerns or engage in binge eating or purging behavior.[29]

Children with anorexia, like older patients, are generally perfectionists, conscientious, and hardworking, but eating disorders have also been recognized in children who are average or poor students. Eating disorders occur in children of all races and ethnicities and are even now seen in children living in poverty.[11]

As with older patients, the prognosis for children with anorexia is variable. If treatment is not effective, the resulting undernutrition is even more likely to cause physical complications such as heart and circulatory failure in children than in older patients. Growth is affected, but the long-term consequences depend on the outcome of treatment. If treatment restores normal eating, these children will catch up in growth. Complications that may persist include amenorrhea, delayed growth, impaired fertility, and osteoporosis.

Eating Disorders in Athletes

The prevalence of eating disorders is higher in athletes than in the general population.[30,31] It is higher in female athletes than in male athletes, and more common among those competing in leanness-dependent and weight-dependent sports such as ballet and other types of dance, figure skating, gymnastics, track and field, diving, cycling, crew, wrestling, and horse racing (Figure F2.11). The highest prevalence of eating disorders among female athletes is seen in endurance and aesthetic sports such as cross country running and gymnastics. In male athletes, eating disorders are more common in weight-class sports such as wrestling and boxing. A review of the literature on the prevalence of disordered eating (abnormal eating behaviors not severe enough to be diagnosed as eating disorders) and eating disorders found that the incidence in female athletes may be as high as 45% and in male athletes as high as 19%.[30]

A number of athlete and sport-specific risk factors contribute to the higher prevalence of eating disorders among athletes.[30] Some of the traits that are desirable in athletes, such as excessive exercise, perfectionism, compliance, overachievement, and obsessive-compulsive tendencies, are associated with eating disorders. The relationship between body weight and performance in certain sports contributes to eating disorders. In such sports, a reduction in body weight can enhance performance, and this success can cause the athlete to continue dieting. In sports with weight classes, weigh-ins trigger rapid weight loss regimens prior to competition, and in aesthetic sports aesthetic evaluation contributes to eating disorders. Coaches create an environment that can either increase or decrease the risk of developing eating disorders. The regimented schedule of an athlete makes it easy to use training diets and schedules, travel, or competition as an excuse to not eat normally and hide the eating disorder.

Both anorexia nervosa and bulimia occur in athletes. Over time, the continued starvation characteristic of anorexia and the purging characteristic of bulimia leads to serious health problems as well as a decline in athletic performance.[32] Starvation can lead to abnormal heart rhythms, low blood pressure, and atrophy of the heart muscle. In young athletes, anorexia may impair growth because energy and nutrient intake are not sufficient to support both growth and activity. Bulimia causes fluid and electrolyte loss and can contribute to dehydration and electrolyte disturbances.

aAbezikus/Istock/Getty Images

FIGURE F2.11 Dance and eating disorders
In athletic activities such as dance, where a small, light body enhances the aesthetic presentation and performance, athletes are motivated to diet to stay thin. This overemphasis on body size can contribute to the development of an eating disorder.

Anorexia Athletica *Anorexia athletica* involves excessive workouts as well as calorie restriction to lose weight and enhance performance. Although it is not formally recognized as an eating disorder by mental health diagnostic manuals, it is similar to eating disorders in that the goal of the behavior is to expend calories to control weight. It is a particular problem in athletes. Extreme training is easy to justify because it is a common belief that serious athletes can never work too hard or too long and pain is accepted as

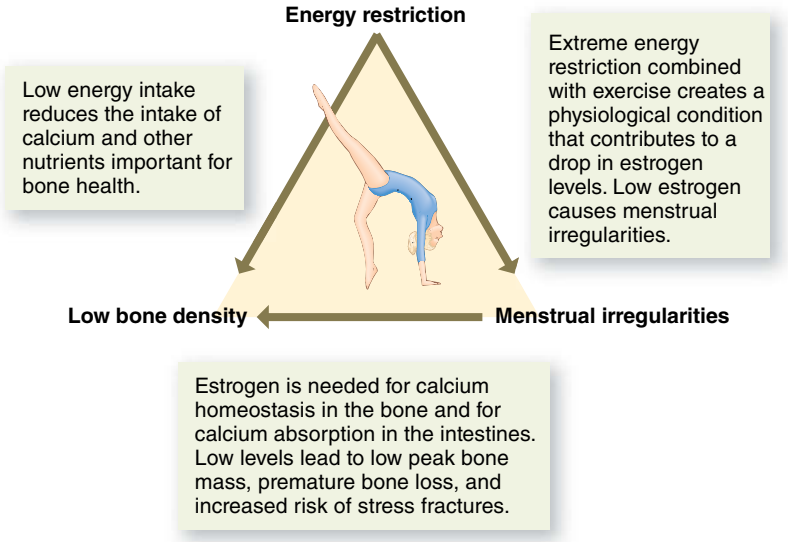


FIGURE F2.12 Female athlete triad
Women with female athlete triad typically have low body fat, do not menstruate regularly, and may experience multiple or recurrent stress fractures. Neither adequate dietary calcium nor the increase in bone mass caused by weight-bearing exercise can compensate for the bone loss caused by low estrogen levels.

an indicator of achievement. Compulsive exercisers will force themselves to exercise even when they don't feel well and may miss social events in order to fulfill their exercise quota. They often calculate exercise goals based on how much they eat. They believe that any break in the training schedule will cause them to gain weight and performance will suffer. Compulsive exercise can lead to eating disorders such as anorexia and bulimia as well as serious health problems including kidney failure, heart attack, and death.

female athlete triad The combination of energy restriction, menstrual irregularities, and low bone density that occurs in some female athletes, particularly those involved in sports in which low body weight and appearance are important.

osteoporosis A bone disorder characterized by a decrease in bone mass, an increase in bone fragility, and an increased risk of fractures.

Female Athlete Triad Female athletes who restrict their energy intake are at risk for a syndrome of interrelated disorders referred to as the **female athlete triad** (see Chapter 13). This syndrome involves low energy availability, menstrual dysfunction, and low bone mineral density, which can progress to a clinical eating disorder, amenorrhea, and **osteoporosis**.[33] Energy restriction creates a physiological condition similar to starvation, which affects hormone levels and leads to menstrual irregularities. Reduced energy availability also contributes to exercise-associated disturbances in the menstrual cycle. The low estrogen levels associated with menstrual irregularities then interfere with calcium balance, leading to reductions in bone mass and bone-mineral density.[34] Low estrogen levels also reduce calcium absorption and, when combined with poor calcium intake (common in female athletes and females in general), lead to premature bone loss, failure to reach maximal peak bone mass, and an increased risk of stress fractures (Figure F2.12). Treatment goals include reversal of weight loss and return of body weight to a level associated with a normal menstrual cycle.[33]

The International Olympic Committee believes that the concept of the female athlete triad should be replaced with a broader syndrome referred to as *Relative Energy Deficiency in Sport (RED-S)*.[35] Their proposal is based on the fact that relative energy deficiency affects many aspects of physiological function in addition to menstrual function and bone health, including metabolic rate, immunity, protein synthesis, growth and development, and cardiovascular and psychological health. In addition, many of the effects of relative energy deficiency affect men, who are not included in the female athlete triad.

Eating Disorders and Diabetes

Diabetes does not cause eating disorders, but it may set the stage for them both physically and emotionally and can be used to hide them. Diabetes is a disease characterized by a chronic elevation in blood glucose that is due to abnormalities in the production or effectiveness of the hormone insulin (see Chapter 4). Treatment involves paying careful attention to diet, exercise,

body weight, and blood glucose levels. The timing of exercise and timing and composition of meals are crucial to good glucose control. This regimentation, which is part of routine diabetes management, may contribute to the development of eating disorders because it places attention on food portions and body weight—a focus similar to that seen in people with eating disorders who do not have diabetes.[36]

Control is a central issue in diabetes, as it is in eating disorders. People with diabetes may feel guilty or out of control if their blood sugar is too high. People with anorexia feel the same way if their weight increases. People with diabetes become consumed with strategies to control blood sugar, and those with an eating disorder become consumed with ways to control weight. Both are preoccupied with weight, food, and diet. Because this is expected in diabetes, people with diabetes can use it to hide anorexia or bulimia. They are supposed to watch what they eat, and the diabetes can be blamed for weight loss.

Those who take insulin to control their diabetes are at particular risk because they can misuse it to control their weight, a condition that has been termed *diabulimia*.[37] Insulin is responsible for allowing glucose to enter muscle and adipose tissue cells. If patients cut back on the amount of insulin they take, the sugar in their blood cannot enter these cells, blood levels rise, and glucose is excreted in the urine. This causes weight loss, but at a very high cost. The long-term complications of high levels of blood glucose include blindness, kidney disease, cardiovascular disease, impaired circulation, and nerve death that can lead to limb amputations. Once people with diabetes start to control their weight by withholding insulin, they are reluctant to stop and may also begin using other inappropriate behaviors to control weight. Sometimes the weight loss seems to improve the diabetes, at least temporarily, by reducing the need for insulin, but if the weight loss continues, it can lead to organ failure and death.

F2.7 Preventing and Getting Treatment for Eating Disorders

LEARNING OBJECTIVES

- Describe factors that predispose people to eating disorders.
- List the steps you could take if you had a friend with an eating disorder.

Reducing the incidence of and morbidity from eating disorders involves action on a number of levels. The first step is to recognize individuals who are at risk. Early intervention can help prevent those who are at risk from developing serious eating disorders, and the actions of family and friends can help those who are affected get help before their health is impaired. To reduce the overall incidence of eating disorders, changes in social attitudes that contribute to their development need to occur.

How to Recognize Those at Risk

To prevent eating disorders, it is important first to identify individuals who are at risk. Excessive concerns about body weight, having friends who are preoccupied with weight, being teased by peers about weight, and problems with one's family all predispose people to eating disorders. There is an association between parental criticism and children's weight preoccupation. Dieting also increases risk. Girls and women who diet are more likely to develop an eating disorder than those who don't diet.[11] Those who have a mother, sister, or friend who diets are also at increased risk. Exposure to media pressure to be thin is also associated with the development of eating disorders.

How to Get Help for a Friend or Family Member

Those who are at risk for eating disorders can be targeted for intervention. For teens, parents play an important role. Arranging an evaluation with a physician and a mental health specialist when the first symptoms are discovered may help prevent the disorder.

TABLE F2.7 Eating Disorders: How to Help

• Get the person to a doctor; the sooner the illness is treated, the more likely a successful outcome will be achieved.
• Talk to the parents, spouse, or other family members.
• Explain your concerns and the potential hazards of the disease.
• Do not expect the person to cooperate; denial is common.
• If you work with the person, contact your employee assistance program.

Once an eating disorder has developed, people usually do not get better by themselves. Helping them to get medical and psychological treatment can avoid severe physical consequences. But getting a friend or relative with an eating disorder to agree to seek help is not always easy. People with eating disorders are good at hiding their behaviors and denying the problem and often do not want help (Table F2.7).

If you suspect a friend has an eating disorder, you can alert a parent, teacher, coach, religious leader, school nurse, or other trusted adult about your concerns or confront your friend or relative yourself and express your concern. If you approach the person yourself, you need to be firm but supportive and caring. The goal in discussing a person's eating disorder is to encourage the person to seek help. However, help is effective only if it is desired. People with eating

disorders are likely to refuse help initially. Therefore, when you approach someone about an eating disorder, it is important to make it clear that you are not trying to force them to do anything they don't want to do. Continued encouragement can help some people to seek professional help. The first reaction of individuals confronted about an eating disorder is often to deny that they have a problem. Support your suspicions with examples of things you have seen that make you believe your friend has a problem. You should be prepared for all possible reactions. People with eating disorders usually try to hide their behaviors, so it is traumatic for them when someone discovers their secret. One person may be relieved that you are concerned and willing to help, whereas another may be angry and defensive.

Reducing the Prevalence of Eating Disorders

Eating disorders are easier to prevent than to cure. The biggest impact on prevention can be made by social interventions that target the elimination of weight-related teasing and criticism from peers and family members. Another important target for reducing the incidence of eating disorders is the media. If the unrealistically thin body ideal presented by the media could be altered, the incidence of eating disorders would likely decrease. Even with these interventions, however, eating disorders are unlikely to go away, but education through schools and communities about the symptoms and complications of eating disorders can help people identify friends and family members at risk and persuade those with early symptoms to seek help.

CHAPTER OUTLINE

8.1 **What Are Vitamins?**
- Vitamins in Our Diet
- Absorption, Storage, and Excretion of Vitamins
- What Vitamins Do
- Meeting Vitamin Needs

8.2 **Thiamin**
- Thiamin in the Diet
- How Thiamin Functions in the Body
- Thiamin Deficiency
- Recommended Thiamin Intake
- Thiamin Toxicity and Supplements

8.3 **Riboflavin**
- Riboflavin in the Diet
- How Riboflavin Functions in the Body
- Riboflavin Deficiency
- Recommended Riboflavin Intake
- Riboflavin Toxicity and Supplements

8.4 **Niacin**
- Niacin in the Diet
- How Niacin Functions in the Body
- Niacin Deficiency
- Recommended Niacin Intake
- Niacin Toxicity and Supplements

8.5 **Biotin**
- Biotin in the Diet
- How Biotin Functions in the Body
- Biotin Deficiency
- Recommended Biotin Intake
- Biotin Toxicity

8.6 **Pantothenic Acid**
- Pantothenic Acid in the Diet
- How Pantothenic Acid Functions in the Body
- Pantothenic Acid Deficiency
- Recommended Pantothenic Acid Intake
- Pantothenic Acid Toxicity

8.7 **Vitamin B_6**
- Vitamin B_6 in the Diet
- How Vitamin B_6 Functions in the Body
- Vitamin B_6 Deficiency
- How Vitamin B_6 Status Is Related to Cardiovascular Disease
- Recommended Vitamin B_6 Intake
- Vitamin B_6 Toxicity and Supplements

8.8 **Folate (Folic Acid)**
- Folate in the Diet and the Digestive Tract
- How Folate Functions in the Body
- Folate Deficiency
- Recommended Folate Intake
- Meeting Folate Needs
- Folate Toxicity

8.9 **Vitamin B_{12}**
- Vitamin B_{12} in the Diet
- Vitamin B_{12} in the Digestive Tract
- How Vitamin B_{12} Functions in the Body
- Vitamin B_{12} Deficiency
- Recommended Vitamin B_{12} Intake
- Vitamin B_{12} Toxicity and Supplements

8.10 **Vitamin C**
- Vitamin C in the Diet
- How Vitamin C Functions in the Body
- Vitamin C Deficiency
- Recommended Vitamin C Intake
- Vitamin C Toxicity and Supplements

8.11 **Choline and Other Vitamin-Like Compounds**

(©iStockphoto)

Kostiantyn Ablazov / Shutterstock

The Water-Soluble Vitamins

8

CASE STUDY

Gary is a graduate student in the history department. His program pays him a small stipend, but it barely covers his rent. Paying for school without racking up too many loans means that he has to keep his food budget down. For breakfast, he has oatmeal with milk. For lunch, he makes a tuna sandwich or occasionally goes out with his friends for a burger and fries. Dinner is usually ramen noodles, macaroni and cheese, or hot dogs. He snacks on soda, candy bars, and chips throughout the day and has ice cream for dessert when he can afford it.

This eating plan worked for Gary because it was inexpensive and filling, but some of his fellow grad students started to question how healthy it was. Gary had to admit he wasn't feeling his best, and he started to suspect that his friends might be right about his diet. His legs had been aching, and he was tired a lot of the time. He decides that a visit to the health center for a medical evaluation would be a good idea.

The doctor took a blood sample to check for anemia and finds that Gary is anemic; he has low levels of the iron-containing protein hemoglobin. The doctor schedules an appointment for him to meet with the dietitian and a quick diet evaluation with a food frequency questionnaire reveals that Gary's limited diet includes little meat and does not include any fruits and vegetables. Because he doesn't eat any fruits and vegetables, his vitamin C intake is very low. Vitamin C promotes iron absorption and is needed for the integrity of small blood vessels. The dietitian thinks that Gary's low intake of vitamin C may have contributed to his anemia and possibly his leg aches. **As a history major, Gary knows that in centuries past the vitamin C–deficiency disease scurvy afflicted sailors and explorers who had limited access to fresh fruits and vegetables.**

© Cat London/iStockphoto

8.1 What Are Vitamins?

LEARNING OBJECTIVES

- Define *vitamin*.
- Discuss the risks and benefits of meeting vitamin needs with foods, fortified foods, and/or dietary supplements.
- Describe how bioavailability affects vitamin requirements.
- Explain how vitamins are involved in energy metabolism.

vitamins Organic compounds needed in the diet in small amounts to promote and regulate the chemical reactions and processes needed for growth, reproduction, and maintenance of health.

water-soluble vitamins Vitamins that dissolve in water.

fat-soluble vitamins Vitamins that dissolve in fat.

Vitamins are organic compounds that are essential in the diet in small amounts to promote and regulate the processes necessary for growth, reproduction, and the maintenance of health. When a vitamin is lacking in the diet, deficiency symptoms occur. When the vitamin is restored to the diet, the symptoms resolve. Vitamins have traditionally been grouped based on their solubility in water or fat. This chemical characteristic allows generalizations to be made about how they are absorbed, transported, excreted, and stored in the body. The **water-soluble vitamins** include the B vitamins and vitamin C. The **fat-soluble vitamins** include vitamins A, D, E, and K (Figure 8.1).

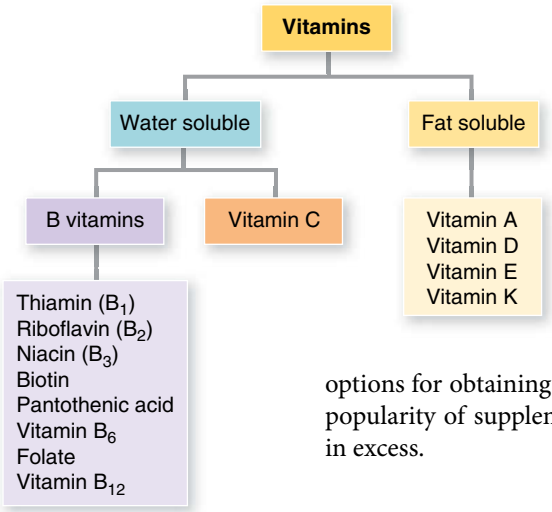


FIGURE 8.1 Water-soluble and fat-soluble vitamins The vitamins were initially named alphabetically in approximately the order in which they were identified: A, B, C, D, and E. The B vitamins were first thought to be one chemical substance but were later found to be many different substances, so the alphabetical name was broken down by numbers. For example, thiamin is B_1, riboflavin is B_2, and niacin is B_3. Vitamins B_6 and B_{12} are the only ones that are still commonly referred to by their numbers.

Vitamins in Our Diet

The last of the 13 compounds recognized as vitamins today was characterized in 1948. The ability to isolate and purify vitamins has allowed them to be added to the food supply and incorporated into pills. As a result, our diet includes not only vitamins that are naturally present in food but also those that have been added to foods and those consumed as dietary supplements. Despite the variety of options for obtaining vitamins, it is still possible to consume too little of some vitamins, and the popularity of supplements has increased the likelihood that certain vitamins will be consumed in excess.

Natural Food Sources of Vitamins Almost all foods contain some vitamins (Figure 8.2). Grains are good sources of most of the B vitamins. Leafy green vegetables provide folate, vitamin A, vitamin E, and vitamin K; citrus fruit provides vitamin C. Meat and fish are good sources of all of the B vitamins, and milk provides riboflavin and vitamins A and D. Even oils provide vitamins; vegetable oils are high in vitamin E. How much of each of these vitamins remains in a food when it reaches the table depends on how the food is handled. Cooking and storage methods can cause vitamin losses. Processing can cause vitamin losses but can also add vitamins and other nutrients to food.

Fortified Foods Fortified foods contain added nutrients. Consuming these foods can be beneficial if the added nutrients are deficient in the diet, but it can also increase the risk of toxicity.

Sometimes nutrients are added to foods to comply with government fortification programs that mandate such additions in order to prevent vitamin or mineral deficiencies and promote health in the population. **Fortification** is an effective way to supplement nutrients that are deficient in the population's diet without having to rely on consumers to alter their food choices or to take nutrient supplements. Which foods are fortified, which nutrients are added, and how much of a nutrient is added depend on the food supply, the needs of the population, and public health policies. In the United States, iodine was first added to salt in the 1920s and vitamin D has been added to cow's milk since the early 1930s. By 1943, most refined grain products were **enriched** with thiamin, riboflavin, niacin, and iron. Today, fortification programs are used throughout the world to increase the intake of nutrients likely to be deficient (see Chapter 18). The levels of nutrients added are based on an amount that is high

fortification A term used to describe the process of adding nutrients to foods.

enriched Refers to a food that has had nutrients added to restore those lost in processing to a level equal to or higher than originally present.

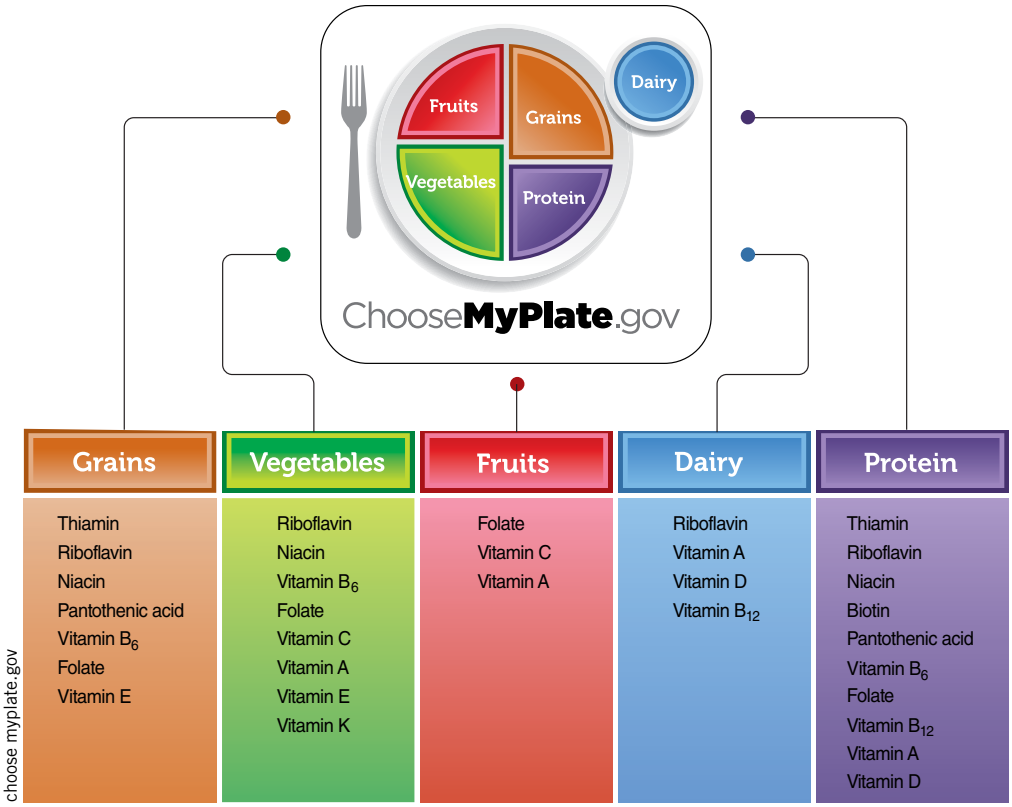


FIGURE 8.2 Vitamins in MyPlate food groups Vitamins are found in foods from all groups, but some groups are lacking in specific vitamins. For example, grains, fruits, and vegetables lack vitamin B_{12}, and grains and protein foods are low in vitamin C.

enough to benefit those who need to increase their intake but not so high as to increase the risk of excessive intakes in others.

Fortification today extends beyond government-mandated programs. Manufacturers are now fortifying their products with a variety of nutrients. Much of this discretionary fortification involves nutrients that are of public health concern. For example, because many Americans do not consume enough calcium, the food industry has supplied us with calcium-fortified orange juice, breakfast cereal, and cheese. Other nutrients that are commonly added are those that are easy and inexpensive to add to a food, and may promote sales of the product. For example, fortifying a snack food such as a Fruit Roll-Up with vitamin C may boost sales because consumers believe it is a healthy choice. But this food is still high in added sugars and much lower in nutrient density than a serving of fresh fruit. The amounts of nutrients added to foods such as breakfast cereals may be arbitrary (Figure 8.3). This indiscriminate fortification of foods can increase the risk of nutrient toxicities (see **Debate: Super-Fortified Foods: Are They a Healthy Addition to Your Diet?**).

Fortified Breakfast Cereal

Nutrition Facts

Serving Size 1 Cup (50g/1.8 oz.)
Servings per Container About 10

Amount Per Serving	Cereal	Cereal with 1/2 Cup Vitamins A&D Fat Free Milk
Calories	180	220
Calories from Fat	5	5
	% Daily Value**	
Total Fat 0.5g*	1%	1%
Saturated Fat 0g	0%	0%
Trans Fat 0g		
Cholesterol 0mg	0%	0%
Sodium 280mg	12%	14%
Potassium 100mg	3%	9%
Total Carbohydrate 35g	12%	14%
Dietary Fiber 2g	9%	9%
Sugars 7g		
Other Carbohydrate 26g		
Protein 3g		
Vitamin A	15%	20%
Vitamin C	25%	25%
Calcium	0%	15%
Iron	100%	100%
Vitamin D	10%	25%
Vitamin E	100%	100%
Thiamin	100%	100%
Riboflavin	100%	110%
Niacin	100%	100%
Vitamin B_6	100%	100%
Folic Acid	100%	100%
Vitamin B_{12}	100%	110%
Pantothenate	100%	100%
Phosphorus	10%	20%
Magnesium	8%	10%
Zinc	100%	100%
Copper	4%	6%

FIGURE 8.3 Nutrients in fortified breakfast cereal Almost all breakfast cereals are fortified with iron and calcium and a complement of vitamins, many of which are not deficient in the U.S. diet. The amounts and variety of nutrients added to some fortified breakfast cereals are so great that they resemble multivitamin/mineral supplements.

Dietary Supplements Dietary supplements are another source of vitamins in our diet. People take them to increase nutrient intake, as well as to energize themselves, promote weight loss, alleviate existing symptoms and conditions, extend life, and prevent chronic disease. Supplement claims are designed to sell products, but there is little evidence that supplements live up to the advertising. However, for some people, taking dietary supplements may be the only way to meet certain nutrient needs because they have low intakes, increased needs, or excess losses (see Chapter 9). For example, supplements of iron and folic acid are recommended for pregnant women, vitamin B_{12} supplements are beneficial for older adults and vegans, and vitamin D supplements may be necessary for individuals with dark skin or limited sun exposure. More information on vitamin and mineral supplements is provided at the end of Chapter 9 and information on individual micronutrient supplements is included in the discussion of each vitamin and mineral in this chapter and in Chapters 9 through 12.

DEBATE

Super-Fortified Foods: Are They a Healthy Addition to Your Diet?

An orange, a tomato, a slice of bread, and a piece of grilled salmon—these are foods that are part of a healthy diet. What about an energy drink with 23 added vitamins and minerals, a protein bar with 100% of your daily vitamin requirements, soft drinks and fruit juice with added calcium, and bottled water fortified with vitamin C? Are products such as these that are fortified with large amounts of nutrients a safe, healthy addition to your diet, or do they pose a risk of toxicity?

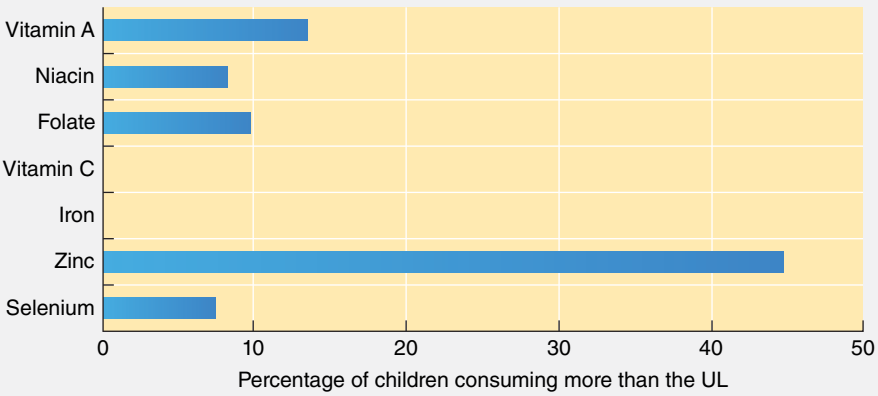
Advocates of super-fortified foods point out that fortified protein bars, juices, and other highly fortified foods provide consumers with a greater variety of nutrient sources and therefore help them meet their nutrient needs. In fact, a review of the sources of nutrients in the American diet found that fortified foods help people from all segments of the population meet their needs, and without fortified foods a high percentage of children and adolescents would have inadequate intakes of many micronutrients.[1,2] These analyses included both mandated and discretionary fortification.

While few would argue the benefits of government-mandated fortification programs, many feel that the discretionary fortification of processed foods increases the risk of nutrient toxicity. Many of the nutrients added to foods by manufacturers to help market their products are ones that are not even low in the population's diet.[3] Some of these products contain levels of nutrients as high as those found in supplements. This is a concern because our decisions about eating foods are different from our decisions about supplements. Typically, we consider the dose when taking a supplement pill. But we eat to satisfy our sensory desires, fill our stomachs, and quench our thirsts. We don't think about whether the food or beverage might provide toxic amounts of nutrients.

The nutrients naturally found in foods are present in relatively small amounts, and the way they are combined limits absorption, making the risk of consuming a toxic amount of a nutrient almost nonexistent. In contrast, it is not difficult to swallow a very high dose of one or more nutrients from excessive servings of super-fortified foods. For example, if you drank the recommended 2 to 3 L of fluid as water fortified with vitamin C, niacin, vitamin E, and vitamin B_6, you could exceed the UL for these vitamins. Then if you also consume 2 cups of fortified breakfast cereal and two protein bars during the day, your risk of toxicity increases even more. While the risk of toxicity is low in adults, when nutrient intake from food and fortified foods was examined, a small proportion of 2- to 18-year-olds had intakes of vitamin A, niacin, and folate that exceeded the UL.[1] The risk could be greater in younger age groups; 45% of 2- to 8-year-olds had zinc intakes from foods plus fortified foods that exceeded the UL (see figure).[2] The government labels these fortified products as foods and we eat them like foods, but they may have the same toxicity risks as supplements.

There is also concern that the appeal of added nutrients may encourage the consumption of processed foods with little intrinsic nutritional value.[3] For example, vitamin C–fortified fruit snacks may be consumed as a source of vitamin C. While this would help children meet their vitamin C requirement, it would also increase their added sugar intake and reduce the likelihood that they will meet their needs for other nutrients.[2]

So, are these products helpful or harmful? It depends on what is in them, how much you consume, and who you are. Should the government get involved in regulating the amounts of nutrients that can be added to all foods? The answer depends on your view of the government's role in food regulation. Should we be gobbling down super-fortified foods without a thought? Probably not.



This graph shows the percentage of children 2 to 8 years of age whose usual intakes of these nutrients are equal to or greater than the UL. These percentages consider the nutrients intrinsic in foods and those added in fortification, but do not include nutrients from dietary supplements. The percentage exceeding the UL would be even greater if supplements were included.[2]

THINK CRITICALLY: Should foods fortified with more than the RDA for one or more nutrients carry a warning to avoid overconsumption?

Absorption, Storage, and Excretion of Vitamins

Whether vitamins come from foods, fortified foods, or supplements, they must be absorbed into the body to perform their functions. About 40 to 90% of the vitamins in food are absorbed, primarily in the small intestine (Figure 8.4). The composition of the diet and conditions in the body, however, may influence vitamin bioavailability.

Bioavailability Whether a vitamin is soluble in fat or water is one of the factors affecting bioavailability; that is, how readily a vitamin can be absorbed and utilized by the body. Fat-soluble vitamins are absorbed by simple diffusion. They require fat in the diet for absorption and are poorly absorbed when the diet is very low in fat. The water-soluble vitamins do not require fat for absorption, but many depend on energy-requiring transport systems or must be bound to

THINK CRITICALLY

Why would a very-low-fat diet decrease the absorption of fat-soluble vitamins?

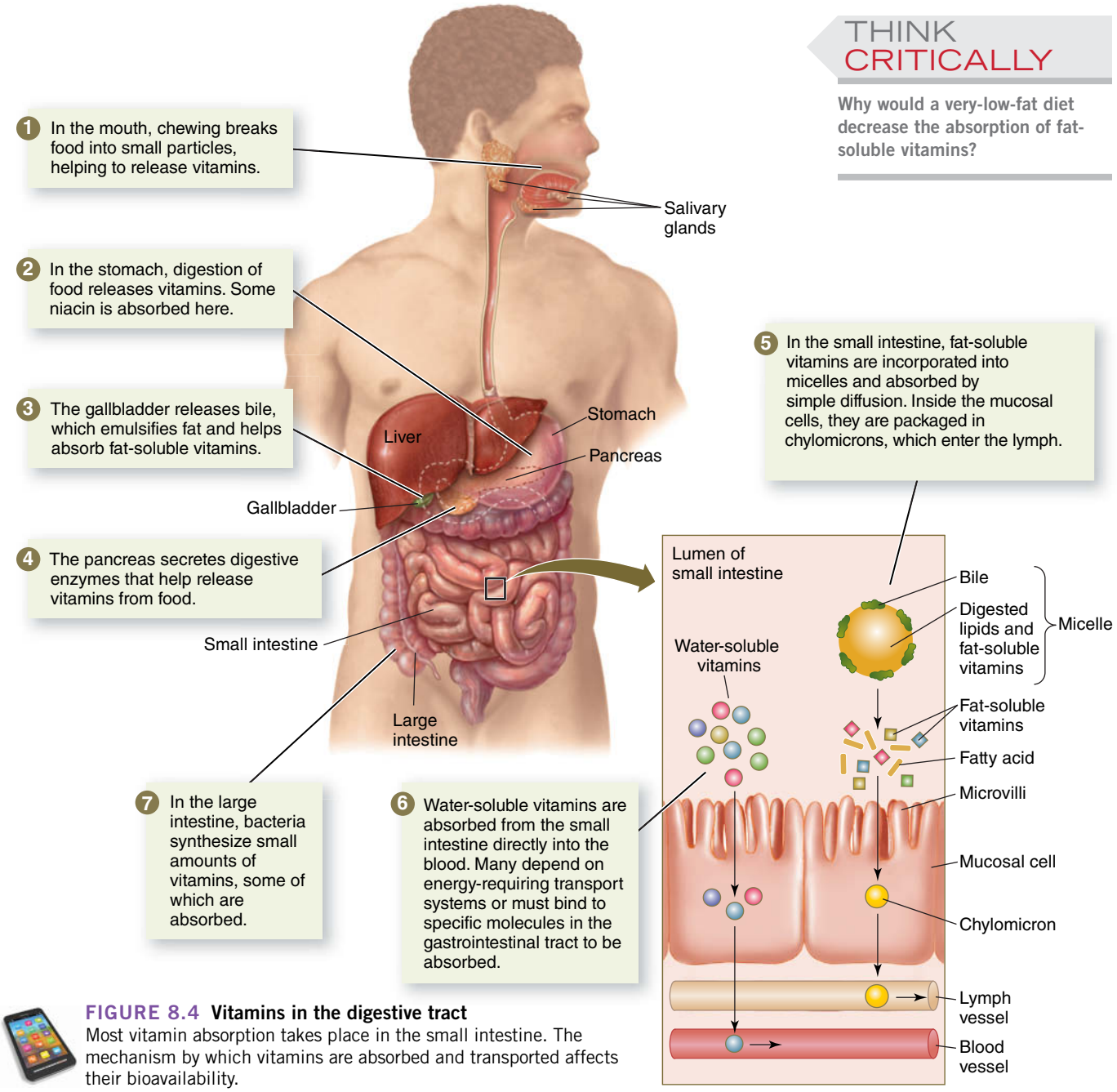


FIGURE 8.4 Vitamins in the digestive tract
Most vitamin absorption takes place in the small intestine. The mechanism by which vitamins are absorbed and transported affects their bioavailability.

specific molecules in the gastrointestinal tract in order to be absorbed. For example, thiamin and vitamin C are absorbed by energy-requiring transport systems, riboflavin and niacin require carrier proteins for absorption, and vitamin B_{12} must be bound to a protein produced in the stomach before it can be absorbed in the small intestine.

Once absorbed into the blood, vitamins must be transported to the cells. Most of the water-soluble vitamins are bound to blood proteins for transport. Fat-soluble vitamins must be incorporated into lipoproteins or bound to transport proteins in order to be transported in the aqueous environment of the blood. For example, vitamins A, D, E, and K are all incorporated into chylomicrons for transport from the intestine (see Chapter 5). Vitamin A is stored in the liver, but it must be bound to a specific transport protein to be transported in the blood to other tissues; therefore, the amount delivered to the tissues depends on the availability of the transport protein.

provitamin or **vitamin precursor** A compound that can be converted into the active form of a vitamin in the body.

coenzyme A small nonprotein organic molecule that acts as a carrier of electrons or atoms in metabolic reactions and is necessary for the proper functioning of many enzymes.

Some vitamins are absorbed in inactive **provitamin** or **vitamin precursor** forms that must be converted into active vitamin forms once inside the body. How much of each provitamin can be converted into the active vitamin and the rate at which this occurs affect the amount of a vitamin available to function in the body.

Storage and Excretion The ability to store and excrete vitamins helps to regulate the amount present in the body. With the exception of vitamin B_{12}, the water-soluble vitamins are easily excreted from the body in the urine. Because they are not stored to any great extent, supplies of water-soluble vitamins are rapidly depleted and they must be consumed regularly in the diet. Nevertheless, it takes more than a few days to develop deficiency symptoms, even when these vitamins are completely absent from the diet. Fat-soluble vitamins, on the other hand, are stored in the liver and fatty tissues and cannot be excreted in the urine. In general, because they are stored to a larger extent, it takes longer to develop a deficiency of fat-soluble vitamins when they are no longer provided by the diet.

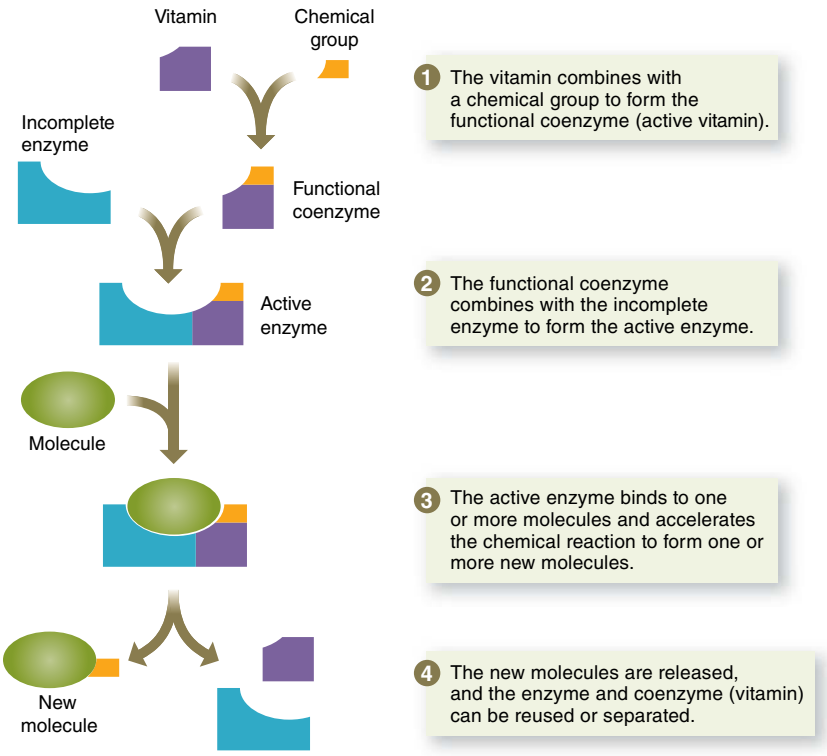


FIGURE 8.5 Coenzymes are needed for enzyme activity
Coenzymes act as carriers of electrons, atoms, or chemical groups that participate in enzyme-catalyzed reactions. All the B vitamins function as coenzymes. There are also coenzymes that are not dietary essentials and therefore are not vitamins.

What Vitamins Do

Vitamins promote and regulate body activities. Each vitamin has one or more important functions. For example, vitamin A is needed for vision as well as normal growth and development. Vitamin K is needed for blood clotting and bone health. Vitamin B_6 plays an important role in amino acid and protein metabolism. Often, more than one vitamin is needed to ensure the health of a particular organ or system; vitamins A, D, K, and C are all needed for healthy bone. Folate and vitamin B_{12} work together to ensure normal cell division. Some vitamins act in a similar manner to do their jobs. For example, all the B vitamins act as **coenzymes** (Figure 8.5). Vitamin C and vitamin E both function as **antioxidants**.

antioxidant A substance that can neutralize reactive oxygen molecules and thereby reduce oxidative damage.

Vitamins do not provide energy; however, they are necessary for energy metabolism. For example, many of the B vitamins are coenzymes essential for the proper functioning of enzymes involved in the metabolism of the energy-yielding nutrients. Without these coenzymes, the reactions that produce ATP cannot proceed (Figure 8.6 and online Focus on Metabolism).

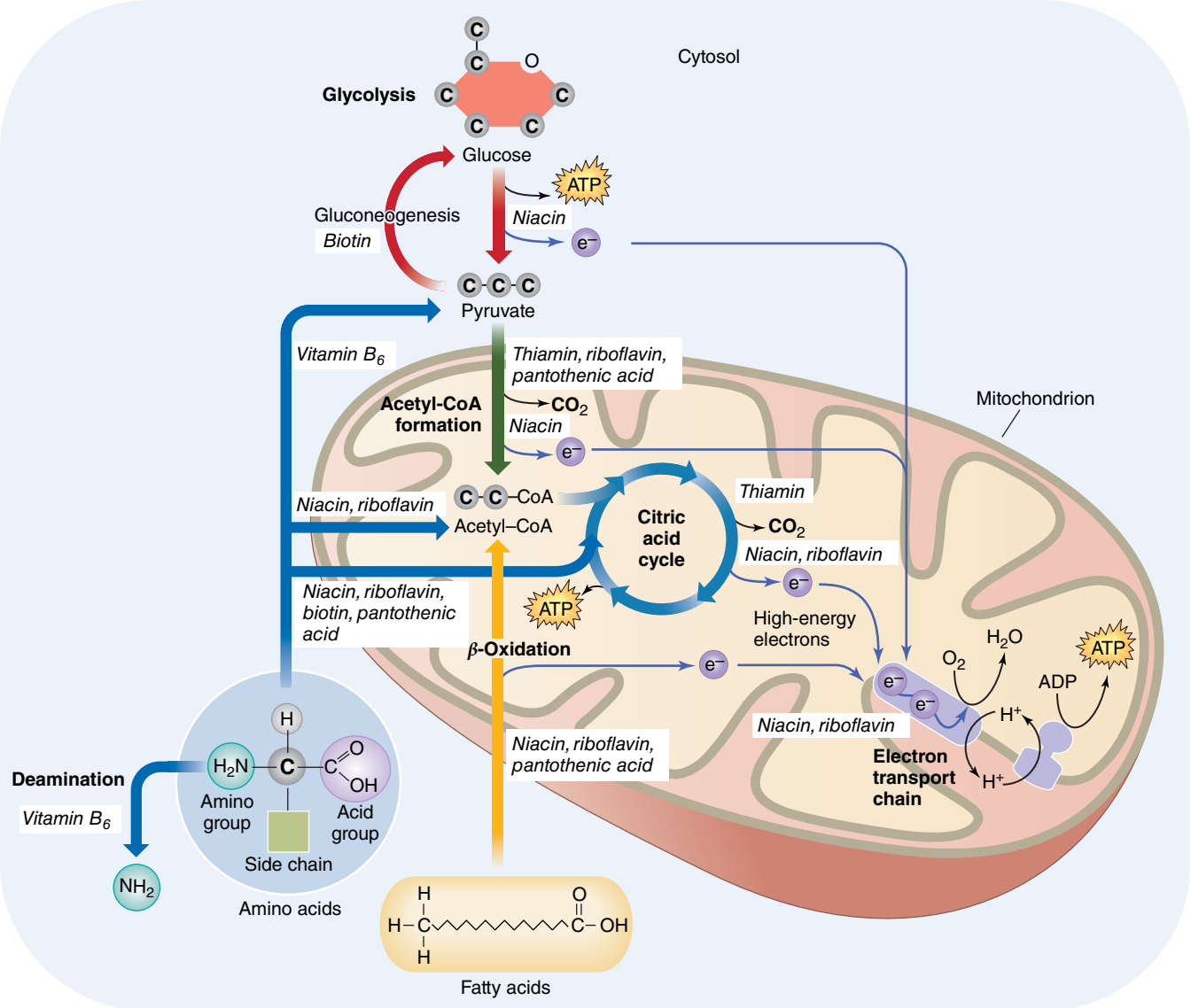


FIGURE 8.6 B vitamins and energy metabolism
Reactions that require thiamin, riboflavin, niacin, biotin, pantothenic acid, or vitamin B_6 as coenzymes are important in the production of ATP from glucose, fatty acids, and amino acids. The enzymes that catalyze the reactions would not function without the vitamin coenzymes shown.

Meeting Vitamin Needs

Today, in the United States and other industrialized countries, an understanding of the sources and functions of the vitamins, a varied food supply, and the ability to fortify foods and supplement nutrients have helped to eliminate severe vitamin deficiencies as a public health problem. For example, niacin deficiency, which was common in the southern United States in the early 1900s, is now almost unheard of; vitamin C deficiency, which has killed countless sailors and soldiers throughout history, is now a rarity; and vitamin A deficiency, which remains a major public health concern worldwide, seldom occurs in developed countries. However, despite all our knowledge, our varied diet, and shelves of vitamin supplements, not everyone gets enough of every vitamin all the time. Certain segments of the population, such as children, pregnant women, and the elderly, are at particular risk for deficiency. Some vitamin deficiencies are on the rise because of changes in dietary patterns. In addition, marginal deficiencies, which may have been present in the population for a long time, are now being recognized and their detrimental effects better understood.

George Semple

FIGURE 8.7 Fresh, frozen, or canned?
Because heat, light, air, and the passage of time all cause foods to lose nutrients, most of us try to purchase fresh produce, but is fresh always highest in vitamins?

Recommended Vitamin Intakes Recommendations for vitamin intake for healthy populations in the United States and Canada are made by the DRIs (see Chapter 2). The RDAs and AIs recommend amounts of each vitamin needed to prevent deficiency and promote health. Because more is not always better when it comes to nutrient intake, the ULs caution against amounts that increase the risk of toxicity (see inside cover). Meeting vitamin needs without exceeding a safe level of intake requires careful attention to the kinds of foods chosen and how they are prepared, as well as knowledge of the nutrients added to foods and those consumed in supplements.

Vitamins on Food Labels Food labels can help identify packaged foods that are good sources of vitamins. Current labels are required to list the amounts of vitamin A and vitamin C in foods as a percentage of the Daily Values and information about other vitamins is often provided voluntarily. These values include the amounts of vitamins naturally found in food as well as those added in processing. The proposed changes to food labels would require that they list vitamin D, which is a vitamin of concern in today's diet. Both the amount in micrograms and the amount as a percentage of the Daily Value would be included. The amounts of vitamin A and vitamin C would not be required because they are no longer considered nutrients at risk in the American diet, but these and other vitamins could be included voluntarily. Fresh fruits, vegetables, and fish, which are excellent sources of many vitamins, do not carry food labels, but most stores voluntarily provide nutrition information for the raw fruits, vegetables, and fish that are most frequently purchased.

The label doesn't tell everything about the vitamin content of foods because vitamins can be lost by exposure to light or oxygen, washed away during preparation, or destroyed by cooking (Figure 8.7). Vitamin losses can be minimized through food preparation methods that reduce exposure to heat and light (Table 8.1).

TABLE 8.1 Tips for Preserving the Vitamins in Your Food

- Store food away from heat and light, and eat it soon after purchasing it.
- Cut fruits and vegetables as close as possible to the time when they will be cooked or served.
- Don't soak vegetables.
- Cook vegetables with as little water as possible by microwaving, pressure-cooking, roasting, grilling, stir-frying, or baking rather than boiling them.
- If foods are cooked in water, use the cooking water to make soups and sauces so that you can retrieve some of the nutrients.
- Don't rinse rice before cooking in order to avoid washing away water-soluble vitamins.

8.2 Thiamin

LEARNING OBJECTIVES

- Name two food groups that provide good sources of thiamin.
- Discuss the role of thiamin in providing energy.
- Explain why a thiamin deficiency causes neurological symptoms.

Thiamin was the first of the B vitamins to be identified and is therefore sometimes called vitamin B_1. **Beriberi**, the disease that results from a deficiency of this vitamin, came to the attention of Western medicine in colonial Asia in the 19th century. Beriberi became such a problem that the Dutch East India Company sent a team of scientists to find its cause. A young physician named Christiaan Eijkman worked on the problem for over 10 years. His success came as a twist of fate. He ran out of food for his experimental chickens, and instead of the usual brown rice, he fed them white rice. Shortly thereafter, the chickens came down with beriberi-like symptoms. When he fed them brown rice again, they got well. The events provided evidence that the cause of beriberi was not a poison or a microorganism, as had previously been thought, but rather something missing from the diet.

beriberi A thiamin deficiency disease that may manifest in one of two forms: dry beriberi, which causes weakness and nerve degeneration, or wet beriberi, which damages the heart.

Knowledge gained from Eijkman's studies made it possible to prevent and cure beriberi by feeding people a diet adequate in thiamin; however, the vitamin itself was not isolated until 1926. We now know that polishing the bran layer off rice kernels to make white rice removes the thiamin-rich portion of the grain. Therefore, in populations where white rice was the staple of the diet, beriberi became a common health problem. The incidence of beriberi in eastern Asia increased dramatically in the late 1800s due to the rising popularity of polished rice.

Thiamin in the Diet

Thiamin is widely distributed in foods (Figure 8.8). A large proportion of the thiamin consumed in the United States comes from enriched grain products such as pasta, rice dishes, baked goods, and breakfast cereals. Pork, whole grains, legumes, nuts, seeds, and organ meats (liver, kidney, heart) are also good sources.

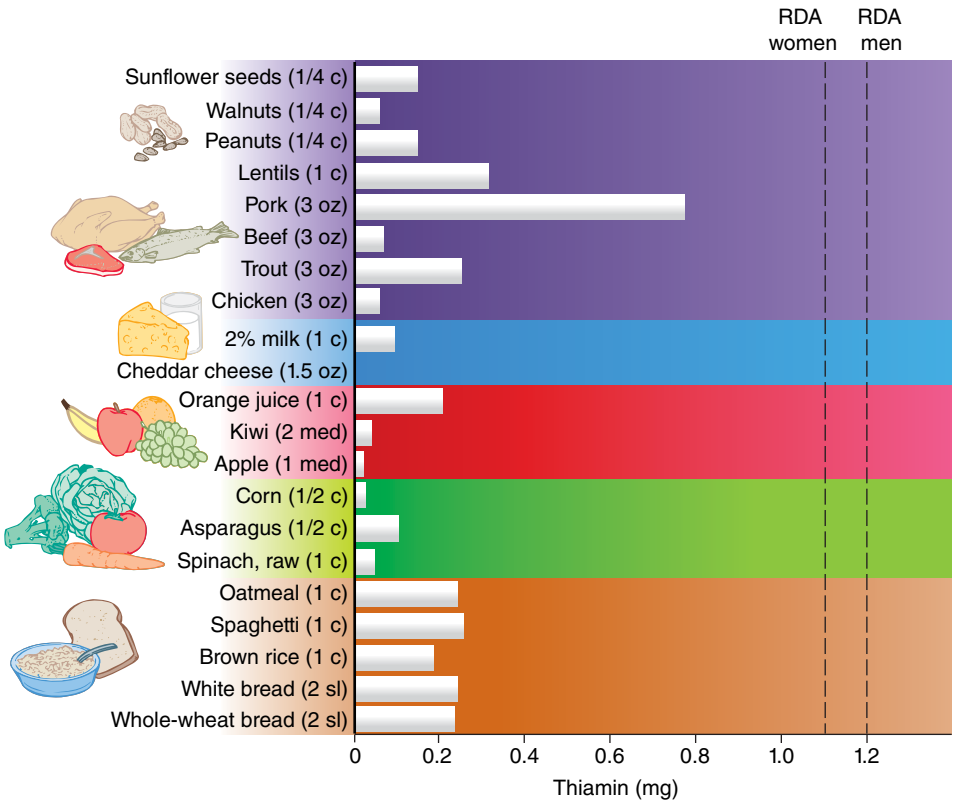


FIGURE 8.8 Thiamin content of MyPlate food groups
A combination of foods from the grains and protein food groups can easily supply the RDA for thiamin (dashed lines).

thiamin pyrophosphate
The active coenzyme form of thiamin. It is the predominant form found inside cells, where it aids reactions in which a carbon-containing group is lost as CO_2.

The thiamin in foods may be destroyed during cooking or storage because it is sensitive to heat, oxygen, and low-acid conditions. Thiamin bioavailability is also affected by the presence of anti-thiamin factors that destroy the vitamin. For instance, raw shellfish and freshwater fish have enzymes that degrade thiamin during food storage and preparation and during passage through the gastrointestinal tract. These enzymes are destroyed by cooking, so they are a concern only in foods consumed raw. Other anti-thiamin factors that are not inactivated by cooking are found in tea, coffee, betel nuts, blueberries, and red cabbage. Because these make thiamin unavailable to the body, habitual consumption of foods containing anti-thiamin factors increases the risk of thiamin deficiency.[4]

How Thiamin Functions in the Body

Thiamin is a vitamin, so it does not provide energy, but it is important in energy metabolism. The active form, **thiamin pyrophosphate**, is a coenzyme for reactions in which a carbon is lost from larger molecules as carbon dioxide. For example, the reaction that forms acetyl-CoA from pyruvate and one of the reactions of the citric acid cycle require thiamin pyrophosphate (see Figure 8.6). Thiamin is therefore essential to the production of ATP from glucose.

Thiamin is also needed for the metabolism of other sugars and certain amino acids; the synthesis of the neurotransmitter acetylcholine; and the production of the sugar ribose, which is needed to synthesize RNA (ribonucleic acid).

Wernicke–Korsakoff syndrome
A form of thiamin deficiency associated with alcohol abuse that is characterized by mental confusion, disorientation, loss of memory, and a staggering gait.

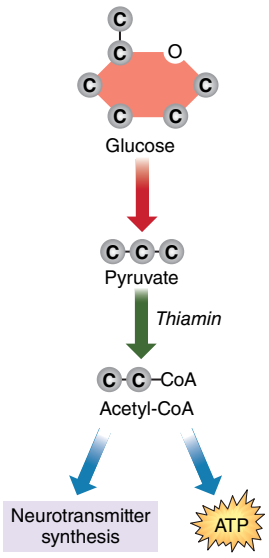
Thiamin Deficiency

Thiamin deficiency results in the disease beriberi. There are two types of beriberi. Dry beriberi causes neurological symptoms such as lethargy, fatigue, and loss of muscle strength. Wet beriberi causes cardiovascular problems such as rapid heartbeat, enlargement of the heart, and congestive heart failure. It is called wet beriberi because fluid accumulates in the lungs and tissues leading to edema, which causes swelling of the legs.

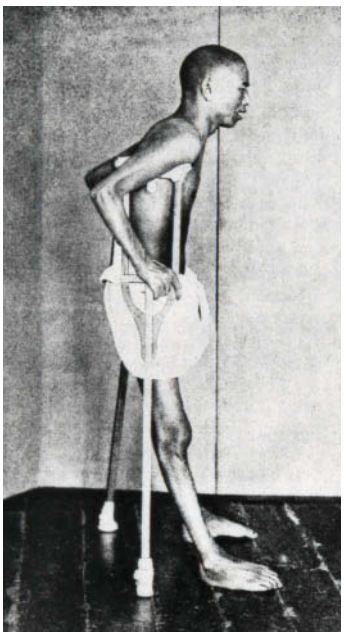
The neurological symptoms of dry beriberi can be explained by the roles of thiamin in glucose metabolism and in the synthesis of the neurotransmitter acetylcholine (Figure 8.9). The earliest symptoms, depression and weakness, which occur after only about 10 days on a thiamin-free diet, may be related to the inability to use glucose completely. Since brain and nerve tissue rely on glucose for energy, the inability to rapidly form acetyl-CoA from pyruvate affects nervous system activity. Lack of acetylcholine may contribute to symptoms such as poor coordination, tingling in the arms and legs, and paralysis. The reason thiamin deficiency causes the cardiovascular symptoms seen with wet beriberi is not well understood.

Overt beriberi is rare in North America today, but thiamin deficiency does occur in alcoholics. These individuals are particularly vulnerable because thiamin absorption is decreased due to the effect of alcohol on the GI tract. In addition, the liver damage that occurs with chronic alcohol consumption reduces conversion of thiamin to the active coenzyme form; thiamin intake also may be low due to a diet high in alcohol and low in nutrient-dense foods. Thiamin-deficient alcoholics may develop a neurological condition known as **Wernicke–Korsakoff syndrome** and characterized by mental confusion, psychosis, memory disturbances, and coma.

FIGURE 8.9 Thiamin deficiency causes beriberi



A. The active thiamin coenzyme (thiamin pyrophosphate) is needed to convert pyruvate into acetyl-CoA. Acetyl-CoA can be used to produce ATP or to synthesize the neurotransmitter acetylcholine. Without thiamin, the body cannot synthesize acetylcholine or properly use glucose, which is the primary fuel for the brain and nerve cells.



U.S. Library of Medicine/Photo Researchers, Inc.

B. For over 1000 years, beriberi flourished in East Asian countries. In Sri Lanka, the word *beriberi* means "I cannot," referring to the extreme weakness and depression that are the earliest symptoms of the disease.

Recommended Thiamin Intake

The RDA for thiamin for adult men ages 19 and older is set at 1.2 mg/day and for adult women 19 and older at 1.1 mg/day. The RDA is based on the amount of thiamin needed to achieve and maintain normal activity of a thiamin-dependent enzyme found in red blood cells and normal urinary thiamin excretion.[5] For an average adult, half of the RDA can be obtained from 4 oz of pork or one-quarter cup of shelled sunflower seeds.

The requirement for thiamin is increased during pregnancy to accommodate the needs of growth and energy utilization, and during lactation to meet the need for increased energy for milk production and to replace the thiamin secreted in milk. Not enough information is available to establish an RDA for infants, so an AI has been set based on the thiamin intake of infants fed human milk. Recommended intakes for all groups are provided on the inside cover.

Thiamin Toxicity and Supplements

Since no toxicity has been reported when excess thiamin is consumed from either food or supplements, a UL for thiamin intake has not been established.[5] This does not mean that high intakes are necessarily safe. Intakes of thiamin above the RDA have not been shown to provide health benefits.

Thiamin supplements containing up to 50 mg/day are widely available and are marketed with the promise that they will provide "more energy." Thiamin is needed to produce ATP, but unless thiamin is deficient, increasing thiamin intake does not increase the ability to produce ATP. Because thiamin deficiency causes mental confusion and damages the heart, supplements often promise to improve mental function and prevent heart disease. However, in the absence of a deficiency, supplements do not have these effects. Thiamin is also included in supplements referred to as B-complex supplements (Table 8.2).

TABLE 8.2 Benefits and Risks of Water-Soluble Vitamin Supplements

Supplement	Claim	Actual benefits or risks
B complex (thiamin, riboflavin, niacin, pantothenic acid, biotin, vitamin B_6, vitamin B_{12})	Increases energy, needed during stress.	Needed for energy metabolism but does not provide energy. Low risk of toxicity except for vitamin B_6.
Niacin (nicotinic acid form)	Lowers cholesterol.	Medicinal doses may reduce cholesterol levels. Causes flushing, tingling, and potentially liver damage. Doses above 35 mg/day should be taken only under medical supervision.
Vitamin B_6	Prevents heart disease; relieves carpal tunnel syndrome (CTS), autism, and premenstrual syndrome (PMS); enhances immune function.	Adequate amounts needed to maintain immune function and normal homocysteine levels, which reduces heart disease risk—excess provides no additional benefit. Supplements may be beneficial for CTS and to reduce the symptoms of PMS. Levels above the UL may cause tingling, numbness, and muscle weakness.
Folate (folic acid)	Prevents birth defects, protects against heart disease and cancer.	Adequate amounts needed to keep homocysteine levels normal, which reduces heart disease risk. Low folate may increase cancer risk. Supplemental sources reduce the risk of birth defects and are recommended for women of childbearing age. May mask a vitamin B_{12} deficiency at high intakes.
Vitamin B_{12}	Prevents heart disease, prevents dementia, reduces fatigue.	Adequate amounts needed for nerve function, for red blood cell synthesis, and to keep homocysteine levels low, which reduces heart disease risk. Supplemental sources recommended for older adults and vegans. No benefit of excess. Low risk of toxicity.
Vitamin C	Prevents colds, reduces cold symptoms, enhances immunity, protects against heart disease and cancer, enhances antioxidant protection.	May reduce the duration of cold symptoms. Important antioxidant but extra as supplements has not been shown to provide additional benefits. Too much can cause GI distress, damage teeth, promote kidney stone formation, and interfere with anticoagulant medications.

8.3 Riboflavin

LEARNING OBJECTIVES

- Explain why milk sold in clear bottles might be low in riboflavin.
- Describe the role of riboflavin in energy metabolism.
- Discuss why other B vitamins are typically deficient when riboflavin is deficient.

While searching for a cure for beriberi, scientists isolated riboflavin and several other B vitamins in addition to thiamin. This occurred because the extracts they made from vegetables and grains could be separated into two components: One contained thiamin, the anti-beriberi factor they sought, and cured beriberi; the other was a mix of B vitamins that was later determined to contain riboflavin along with vitamin B_6, niacin, and pantothenic acid.

flavin adenine dinucleotide (FAD) and **flavin mononucleotide (FMN)** The active coenzyme forms of riboflavin. The structure of these molecules allows them to pick up and donate hydrogens and electrons in chemical reactions.

Riboflavin in the Diet

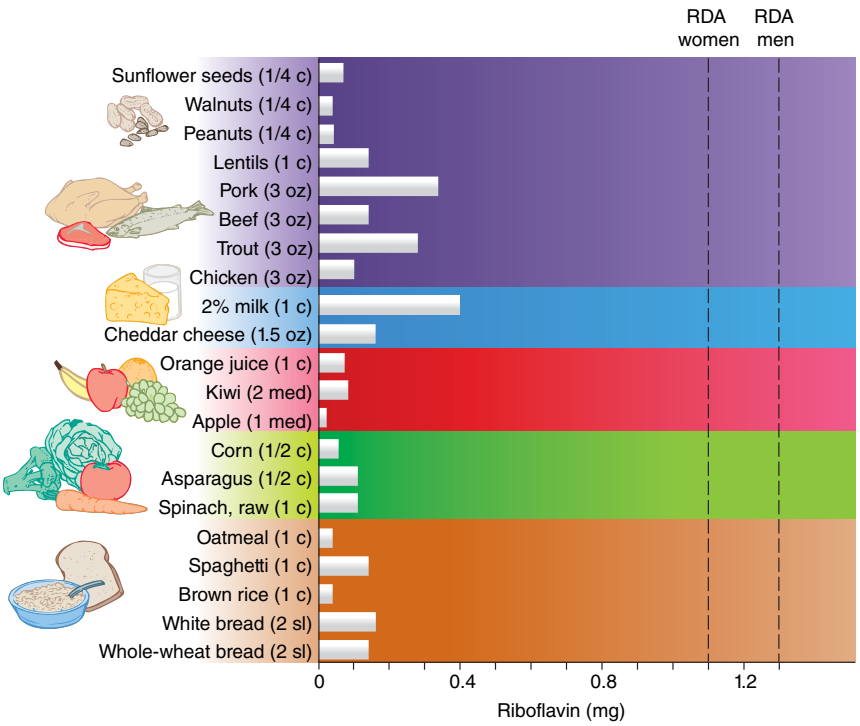
Milk is the best source of riboflavin in the North American diet. Other important sources of this B vitamin include liver, red meat, poultry, fish, and whole and enriched grains. Vegetable sources include asparagus, broccoli, mushrooms, and leafy green vegetables such as spinach (Figure 8.10A). Because riboflavin is destroyed by exposure to light, poor handling decreases a food's riboflavin content. This is a problem when milk is stored in clear containers and exposed to light. Cloudy plastic milk bottles block some light, partially protecting the riboflavin, but cardboard or opaque plastic milk containers are even better at preventing losses (Figure 8.10B).[6]

Metabolism

How Riboflavin Functions in the Body

Riboflavin forms the active coenzymes **flavin adenine dinucleotide (FAD)** and **flavin mononucleotide (FMN)**. FAD functions in the citric acid cycle and is important for the breakdown

FIGURE 8.10 Riboflavin in foods



A. This graph of the riboflavin content of foods from different MyPlate food groups shows that milk, meats, and whole and enriched grains are good sources of riboflavin but a combination of foods is needed to supply the RDA (dashed lines).

Jupiter Images/FoodPix/Getty Images, Inc.

B. Ever wonder why milk doesn't come in glass bottles anymore? One reason is that riboflavin is destroyed by light. Exposure to light can also cause an "off" flavor in the milk and losses of vitamins A and D.[6]

of fatty acids. Both FAD and FMN function as electron carriers in the electron transport chain (see Figure 8.6). Therefore, adequate riboflavin is crucial in providing energy from carbohydrate, fat, and protein. Riboflavin is also involved directly or indirectly in converting a number of other vitamins, including folate, niacin, vitamin B_6, and vitamin K, into their active forms.

Riboflavin Deficiency

When riboflavin is deficient, injuries heal poorly because new cells cannot grow to replace the damaged ones. Tissues that grow most rapidly, such as the skin and the linings of the eyes, mouth, and tongue, are the first to be affected by a deficiency. Symptoms of riboflavin deficiency, called **ariboflavinosis**, include inflammation of the eyes, lips, mouth, and tongue; scaly, greasy skin eruptions; cracking of the tissue at the corners of the mouth; and confusion. Deficiency symptoms may develop after approximately two months on a riboflavin-poor diet.

ariboflavinosis A condition resulting from a deficiency of riboflavin characterized by inflammation of the eyes, lips, mouth, and tongue.

A deficiency of riboflavin is rarely seen alone. It usually occurs in conjunction with deficiencies of other B vitamins. One reason is that the food sources of B vitamins are similar. Therefore, a deficiency of riboflavin due to poor diet will likely lead to multiple vitamin deficiencies. Because riboflavin is needed to convert other vitamins into their active forms, some of the symptoms seen with riboflavin deficiency are actually due to deficiencies in these other nutrients.

Recommended Riboflavin Intake

The RDA for riboflavin for adult men ages 19 and older is 1.3 mg/day and for adult women 19 and older, 1.1 mg/day. This recommendation is based on the amount of riboflavin needed to maintain normal activity of a riboflavin-dependent enzyme in red blood cells and normal riboflavin excretion in the urine.[5] Two cups of milk provide about half the daily amount of riboflavin recommended for a typical adult. The recommended intake can be met without milk if the daily diet includes two to three servings of meat and four to five servings of enriched grain products and high-riboflavin vegetables, such as spinach.

Additional riboflavin is recommended during pregnancy to support growth and increased energy utilization, and during lactation to allow for the riboflavin secreted in milk. Not enough information is available to establish an RDA for infants, so an AI has been set based on the amount of riboflavin consumed by infants fed human milk (see inside cover).

Riboflavin Toxicity and Supplements

No adverse effects have been reported from overconsumption of riboflavin from foods or supplements, and sufficient data to establish a UL for this vitamin are not available. Large doses of riboflavin are not well absorbed, and it is readily excreted in the urine. A harmless side effect of high riboflavin intake, such as may be obtained from over-the-counter supplements, is bright yellow urine.

As with thiamin, the role of riboflavin in energy metabolism has led to claims that supplements containing riboflavin, such as B-complex supplements, will provide an energy boost (see Table 8.2). Although riboflavin is needed for energy metabolism, it does not provide energy. Since a deficiency causes skin and eye symptoms, riboflavin has also been suggested as a cure for eye diseases and skin disorders. However, in the absence of a deficiency, supplementation does not affect the eyes or skin.

8.4 Niacin

LEARNING OBJECTIVES

- Discuss why a niacin deficiency is more likely in someone consuming a limited diet that is based on corn.
- Explain the role of niacin in energy metabolism.
- List the three Ds of pellagra.

pellagra A disease resulting from a deficiency of niacin that causes dermatitis, diarrhea, dementia, and, if not treated, death.

A deficiency of the B vitamin niacin results in a disease called **pellagra**, which causes progressive physical and mental deterioration. It was first observed in Europe in the 18th century, and in the early 20th century it became endemic in the southeastern United States. At the time,

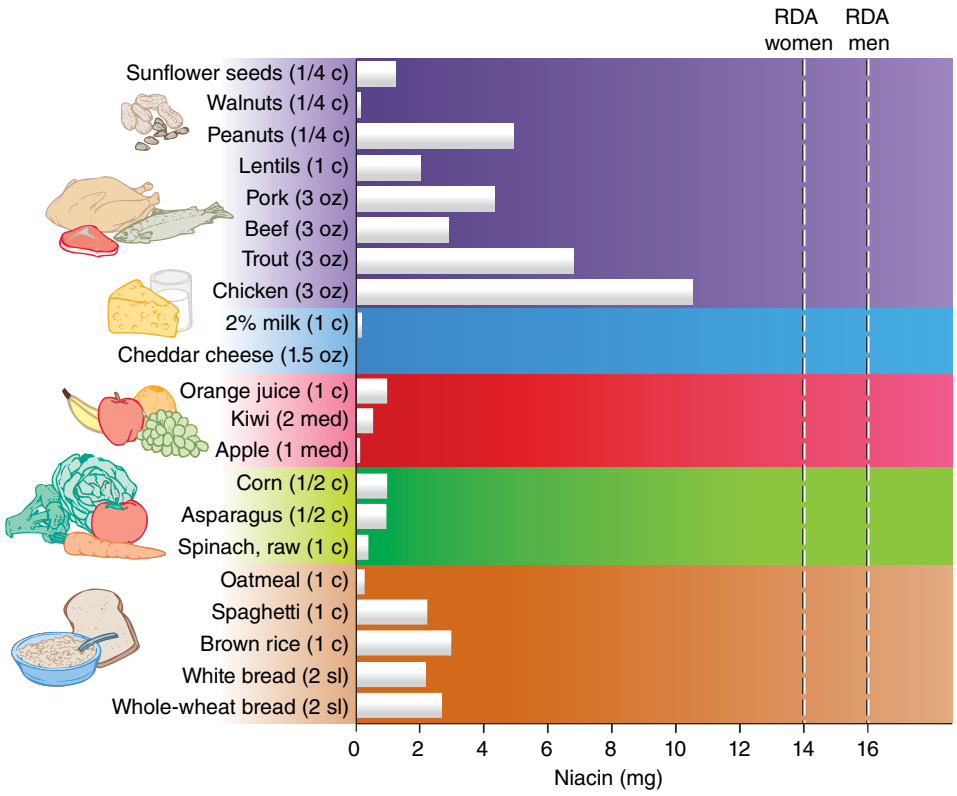
many believed that it was caused by an infection rather than a deficiency in the diet (see **Science Applied: Pellagra: Infectious Disease or Dietary Deficiency?**). The emergence of pellagra can be traced to the cultivation of corn, which is a poor source of niacin, as a dietary staple.[7] It primarily affects people who consume a very limited diet.

Niacin in the Diet

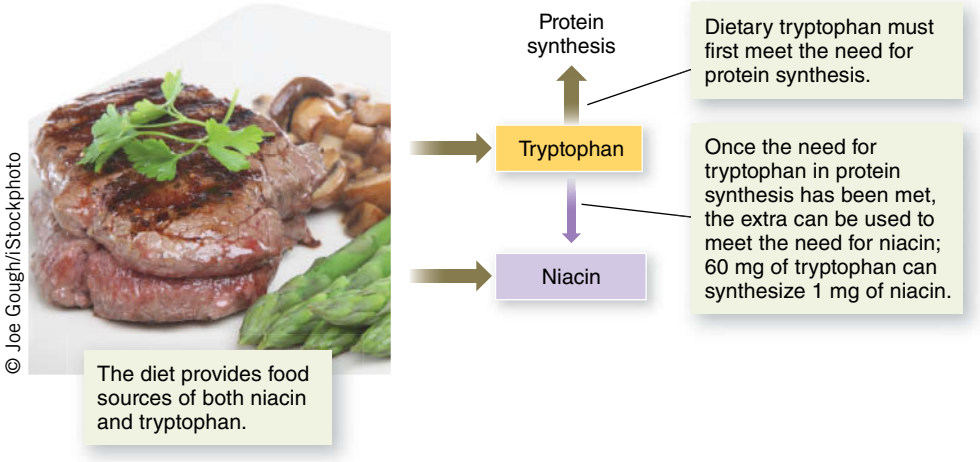
Meat and fish are good sources of niacin (Figure 8.11A). Other sources include legumes, mushrooms, wheat bran, asparagus, and peanuts. Niacin added to enriched flours used in baked goods provides much of the usable niacin in the North American diet. Niacin can also be synthesized in the body from the essential amino acid tryptophan (Figure 8.11B). In a diet that contains high-protein foods such as milk and eggs, which are poor sources of niacin but good sources of tryptophan, much of the need for niacin can be met by tryptophan. Tryptophan, however, is used to make niacin only if enough is available first to meet the needs of protein synthesis. When

FIGURE 8.11 Sources of niacin

A. This graph of the niacin content of foods in different MyPlate food groups shows that meat, legumes, and whole and enriched grains are good sources of niacin; the dashed lines represent the RDAs for adult men and women.



B. We consume both niacin and the essential amino acid tryptophan in our diet. Tryptophan can be used to synthesize niacin but only after the need for tryptophan in protein synthesis has been met.



SCIENCE APPLIED

Pellagra: Infectious Disease or Dietary Deficiency?

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

In the early 1900s, psychiatric hospitals in the southeastern United States were filled with patients with dementia due to the disease pellagra. Although we now know pellagra is due to a niacin deficiency, at the time it was thought to be caused by an infectious agent or toxin. Annually 100,000 people were affected by pellagra, 3000 of them fatally. The federal government established the Thompson–McFadden Pellagra Commission and the U.S. Public Health Service selected Dr. Joseph Goldberger to investigate the cause of the disease and hopefully find a cure.

THE SCIENCE

Investigators with the Pellagra Commission believed that pellagra was caused by an infection. They injected monkeys and baboons with blood, urine, and other extracts from patients with pellagra, but none developed the disease. These results supported the view that pellagra was not due to an infectious agent, yet they still believed that pellagra could be transmitted in some way from a pellagrous to a nonpellagrous person: Perhaps monkeys and baboons were not susceptible to pellagra.[7]

Goldberger studied the communities and institutions where pellagra was common: Pellagra was prevalent among patients in institutions but not among attendants and nurses—a fact that did not support an infectious nature. Goldberger observed that the patients were fed a diet typical of the Southern poor: corn meal, molasses, and fatback or salt pork. The staff ate a more varied diet. By adding milk, eggs, and more meat to the patients' diets, Goldberger was able to cure pellagra. The next step in supporting his hypothesis that pellagra was caused by a dietary deficiency was to bring about pellagra in healthy people by feeding them the deficient institutional diet. In 1915, at a Mississippi State Penitentiary work farm, 12 convicts volunteered to be fed a diet of corn meal, grits, cornstarch, white wheat flour, white rice, cane syrup, sugar, sweet potatoes, a few green vegetables, and a liberal amount of pork fat. After six months, six men developed pellagra. Goldberger concluded that the cause of the disease was a deficiency of an amino acid, a mineral, a fat-soluble vitamin, or some unknown vitamin factor.

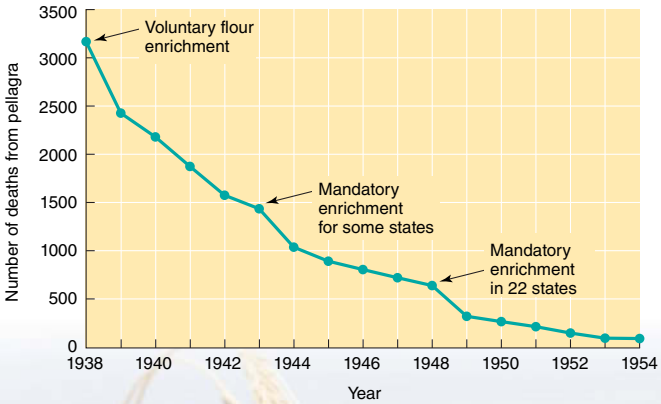
To provide the final proof that pellagra was not due to an infectious agent, Goldberger and 15 of his colleagues voluntarily injected themselves with blood, swabbed their throats with nasal secretions, and swallowed urine, feces, and skin cells from patients who were severely ill with pellagra (later in the experiment, they put the feces and other materials in capsules). After six months, neither he nor his colleagues had become ill. Goldberger proved that pellagra was not an infectious disease and continued searching for the missing dietary factor.

Despite Goldberger's efforts, the epidemic raged on. Experiments with dogs had demonstrated that yeast and liver could cure pellagra, but nothing had been done to change the Southern diet that caused the deficiency. Joseph Goldberger died in 1929, the year the epidemic reached its peak. In 1937, another research team identified the pellagra-preventive factor as nicotinic acid.

THE APPLICATION

The work of Goldberger and his successors showed us the cause of pellagra and that it could be prevented and cured by adding meat, eggs, milk, yeast, and other niacin-rich foods to the diet. Despite this understanding, poor dietary habits, poverty, and chronic malnutrition allowed this curable disease to continue until the 1940s when the enrichment of grains helped to eliminate it.[8]

In 1936, the Council on Foods and Nutrition of the American Medical Association recommended the fortification of food. In 1938, bakers began using high-vitamin yeast, which added protein, niacin, and other B vitamins to baked goods (see graph).[9] In the 1940s, the recommendations of the Committee on Food and Nutrition, now the Food and Nutrition Board, led to the enrichment of flour with thiamin, riboflavin, niacin, and iron.[10] The fortification of foods with nutrients that are deficient in a population's diet is now used throughout the world to improve nutrient intake and prevent deficiency diseases.



In 1938, bakers voluntarily began enriching flour with B vitamins, a move that led to a decline in mortality from pellagra. By the early 1940s, enrichment of flour was becoming mandatory. This measure, along with the economic boom created by World War II, led to a rapid and dramatic decline in pellagra mortality.

© Bon Appetit/Alamy Limited

FIGURE 8.12 Beans and tortillas provide niacin
The treatment of corn with lime water during the preparation of tortillas improves niacin bioavailability. Serving tortillas alongside beans, which are a good source of niacin, has helped prevent pellagra in Mexico and other Latin American countries with a corn-based diet.

the diet is low in tryptophan, it is not used to synthesize niacin. Food composition tables and databases list only preformed niacin in a food, not the amount of niacin that can be made from tryptophan contained within the food.

The association between niacin deficiency and a limited diet based on corn has been attributed to the low-tryptophan content of corn and the fact that the niacin found naturally in corn (and to a lesser extent in other cereal grains) is bound to other molecules and therefore not well absorbed. The treatment of corn with lime water (water and calcium hydroxide), as is done in Mexico and Central America during the making of tortillas, enhances the availability of niacin. The diet in these regions also contains legumes, which provide both niacin and a source of tryptophan for the synthesis of niacin (Figure 8.12). As a result, despite their corn-based diet, populations in these regions have not suffered from pellagra. Today, pellagra remains common in India and parts of China and Africa.[11] Efforts to eradicate this deficiency include the development of new varieties of corn that provide more available niacin and more tryptophan than traditional varieties.

How Niacin Functions in the Body

Niacin is important in the production of ATP from the energy-yielding nutrients as well as in reactions that synthesize other molecules. The two forms of niacin are nicotinic acid and nicotinamide. Either form can be used by the body to make the two active coenzymes **nicotinamide adenine dinucleotide (NAD)** and **nicotinamide adenine dinucleotide phosphate (NADP)**. NAD functions in glycolysis and the citric acid cycle, accepting released electrons and passing them on to the electron transport chain where their energy is trapped and used to convert ADP to ATP (see Figure 8.6). NADP acts as an electron carrier in reactions that synthesize fatty acids and cholesterol.

Metabolism

nicotinamide adenine dinucleotide (NAD) and **nicotinamide adenine dinucleotide phosphate (NADP)** The active coenzyme forms of niacin that can pick up and donate hydrogens and electrons. They are important in the transfer of electrons to oxygen in cellular respiration and in many synthetic reactions.

Niacin Deficiency

The need for niacin is so widespread in metabolism that a deficiency causes damage throughout the body. The early symptoms of pellagra include fatigue, decreased appetite, and indigestion, followed by the three Ds: dermatitis, diarrhea, and dementia. If left untreated, niacin deficiency results in a fourth D—death. The dermatitis resembles sunburn and strikes parts of the body exposed to sunlight, heat, or injury (Figure 8.13). Gastrointestinal symptoms include a bright-red tongue and may include vomiting, constipation, or diarrhea. Mental symptoms begin with irritability, headaches, loss of memory, insomnia, and emotional instability and progress to psychosis and acute delirium.

Recommended Niacin Intake

niacin equivalents (NEs) The measure used to express the amount of niacin present in food, including that which can be made from its precursor, tryptophan. One NE is equal to 1 mg of niacin or 60 mg of tryptophan.

The RDA for niacin is expressed as **niacin equivalents (NEs)**. One NE is equal to 1 mg of niacin or 60 mg of tryptophan. This allows for the fact that some of the requirement for niacin can be met by the synthesis of niacin from tryptophan. To estimate the niacin contributed by high-protein foods, protein is assumed to be about 1% tryptophan. The criterion used to estimate the average niacin requirement is urinary excretion of niacin metabolites. The RDA for adult men and women of all ages is 16 and 14 mg NE per day, respectively.[5] A meal containing a medium chicken breast and a cup of steamed asparagus provides this amount.

LIFE CYCLE

Niacin needs are increased during pregnancy to account for the increase in energy expenditure and during lactation to account for both the increase in energy expenditure and the niacin secreted in milk. Not enough information is available to establish an RDA for infants, so an AI has been set based on the amount of niacin found in human milk (see inside cover).

Niacin Toxicity and Supplements

There is no evidence of any adverse effects from consumption of niacin naturally occurring in foods, but supplements can be toxic. The adverse effects of high intakes of niacin include flushing of the skin, a tingling sensation in the hands and feet, a red skin rash, nausea, vomiting, diarrhea, high blood sugar levels, abnormalities in liver function, and blurred vision. Since flushing is the first toxicity symptom to appear as the dose is increased, the UL for adults has been set at 35 mg/day, the highest level that is unlikely to cause flushing in the majority of healthy people. This value applies to the forms of niacin contained in supplements and fortified foods but does not include niacin naturally occurring in foods.

Niacin is a commonly used vitamin supplement that is included in multivitamins as well as in B-complex vitamin supplements marketed to give you more energy. High doses of this vitamin are also used as a medication to treat elevated blood cholesterol (see Table 8.2). Doses of 50 mg/day or greater of the nicotinic acid form of niacin have been found to decrease blood levels of LDL cholesterol and triglycerides and increase HDL cholesterol.[12] Since the UL for niacin is only 35 mg/day, many people are unable to take niacin as a cholesterol-lowering drug because they experience side effects due to niacin toxicity. Because niacin supplements are available over the counter, people may try to treat themselves for high blood cholesterol, but high doses of vitamins are as dangerous as drugs and should be used only with medical supervision.

Dr. M.A. Ansary/SPL/Photo Researchers

FIGURE 8.13 Pellagra
The cracked, inflamed skin characteristic of pellagra most commonly appears on areas exposed to sunlight or other stresses.

8.5 Biotin

LEARNING OBJECTIVES

- Explain why consuming raw eggs might cause a biotin deficiency.
- Discuss why an AI rather than an RDA has been established for biotin.

Biotin was discovered when rats fed protein from raw egg white developed a syndrome of hair loss, dermatitis, and neuromuscular dysfunction. The symptoms were due to a deficiency of biotin. The deficiency was caused by a protein in raw egg white, called *avidin*, which tightly binds biotin and prevents its absorption.

Biotin in the Diet

Good dietary sources of biotin include liver, egg yolks, yogurt, and nuts. Fruit and meat are poor sources. Foods containing raw egg whites should be avoided not only because avidin binds biotin and prevents its absorption but because raw eggs also may be contaminated with *Salmonella* bacteria, which can cause food-borne illness (**Figure 8.14** and Chapter 17). Thoroughly cooking eggs destroys bacteria and denatures avidin so that it cannot bind biotin.

A Carmichael/Getty Images, Inc.

FIGURE 8.14 Raw eggs can be dangerous
Drinking raw eggs or shakes containing raw eggs is a common practice among body builders. Cooked eggs provide just as much protein and do not reduce biotin absorption or pose a risk for *Salmonella* infection.

How Biotin Functions in the Body

Biotin is a coenzyme for a group of enzymes that adds the acid group COOH to molecules. It functions in energy metabolism because it is needed to make a four-carbon molecule necessary in the citric acid cycle and in gluconeogenesis. This B vitamin is also important in the synthesis of fatty acids and some amino acids (see Figure 8.6).

Metabolism

Biotin Deficiency

Although biotin deficiency is uncommon, it has been observed in people with malabsorption or protein-energy malnutrition, those receiving tube feedings or total parenteral nutrition without

biotin, those taking anticonvulsant drugs for long periods, and those frequently consuming raw egg whites.[5] When biotin intake is deficient, symptoms including nausea, thinning hair, loss of hair color, a red skin rash, depression, lethargy, hallucinations, and tingling of the extremities gradually appear.

Recommended Biotin Intake

A dietary requirement for biotin has been difficult to estimate because some biotin is produced by bacteria in the gastrointestinal tract and absorbed into the body. Therefore, no RDA could be determined, but an AI of 30 μg/day has been established for adult men and women based on the amount of biotin found in a typical North American diet.[5]

No additional biotin is recommended for pregnancy, but the AI is increased during lactation to account for the amount secreted in milk. The AI for infants is based on the amount of biotin consumed by infants fed human milk.

Biotin Toxicity

No toxicity has been reported in patients given 200 mg/day of biotin to treat various disease states, and sufficient data are not available to establish a UL.[5]

8.6 Pantothenic Acid

LEARNING OBJECTIVES

- Discuss why pantothenic acid deficiency is rare.
- Explain why pantothenic acid is said to be needed "everywhere" in the body.

Pantothenic acid, which gets its name from the Greek word *pantothen* (meaning "from everywhere"), is a B vitamin that is widely distributed in foods.

Pantothenic Acid in the Diet

Pantothenic acid is particularly abundant in meat, eggs, whole grains, and legumes. It is found in lesser amounts in milk, vegetables, and fruits (Figure 8.15). Pantothenic acid is susceptible to damage by exposure to heat and low- or high-acid conditions.

How Pantothenic Acid Functions in the Body

In addition to being "from everywhere" in the diet, pantothenic acid seems to be needed everywhere in the body. It is part of CoA, a coenzyme needed for the breakdown of carbohydrates, fatty acids, and amino acids, as well as for the modification of proteins and the synthesis of neurotransmitters, steroid hormones, and hemoglobin. Pantothenic acid is also needed for the activity of acyl carrier protein, which is needed for the synthesis of cholesterol and fatty acids (see Figure 8.6).

Pantothenic Acid Deficiency

The wide distribution of pantothenic acid in foods makes deficiency rare in humans. A deficiency of this vitamin alone has not been reported, but it may occur as part of a multiple–B vitamin deficiency resulting from malnutrition or chronic alcoholism.

Recommended Pantothenic Acid Intake

There is no RDA for pantothenic acid, but an AI of 5 mg/day has been recommended for adult men and women.[5] This value is based on the intake of pantothenic acid sufficient to replace

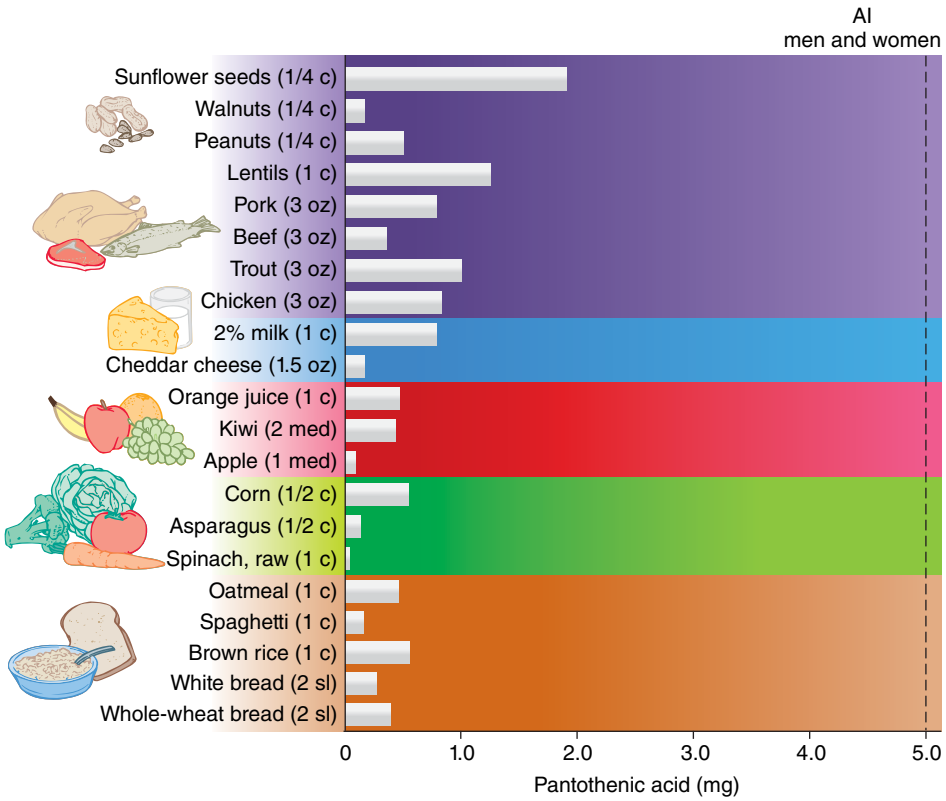


FIGURE 8.15 Pantothenic acid content of MyPlate food groups
All food groups in MyPlate contain good sources of pantothenic acid; the dashed line represents the AI for adult men and women.

urinary losses. The AI is increased to 6 and 7 mg/day to meet the needs of pregnancy and lactation, respectively.

Pantothenic Acid Toxicity

Pantothenic acid is relatively nontoxic. No toxicity symptoms were reported in a study that fed young men 10 g of pantothenic acid per day for six weeks. Another study found that doses of 10 to 20 g/day may result in diarrhea and water retention.[5] Data are not sufficient to establish a UL for pantothenic acid.

8.7 Vitamin B_6

LEARNING OBJECTIVES

- Name two animal products and two plant products that are good sources of vitamin B_6.
- Explain the role of vitamin B_6 in amino acid metabolism.
- Describe the relationship between vitamin B_6 and heart disease.

Vitamin B_6 is particularly important for amino acid and protein metabolism. This B vitamin was identified only when a deficiency syndrome was discovered that did not respond to thiamin or riboflavin supplementation.

Vitamin B_6 in the Diet

Vitamin B_6 is found in both animal and plant foods. Animal sources include chicken, fish, pork, and organ meats. Good plant sources include whole-wheat products, brown rice, soybeans, sunflower seeds, and some fruits and vegetables such as bananas, broccoli, and spinach

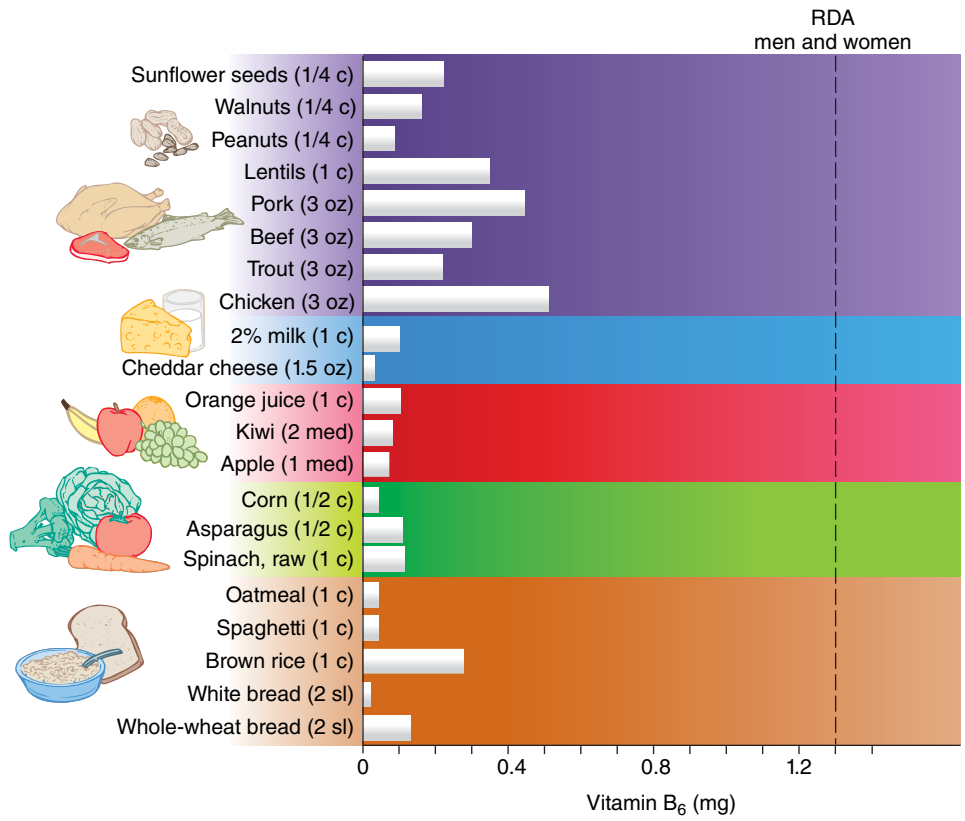


FIGURE 8.16 Vitamin B_6 content of MyPlate food groups
Meats, legumes, and whole grains are the best sources of vitamin B_6; the dashed line represents the RDA for adults ages 50 and younger.

(Figure 8.16). Vitamin B_6 is easily destroyed by exposure to heat and light and is easily lost in processing. It is not added back in the enrichment of grain products, but most breakfast cereals are fortified with vitamin B_6.

How Vitamin B_6 Functions in the Body

Metabolism

pyridoxine The chemical term for vitamin B_6.

pyridoxal phosphate The major coenzyme form of vitamin B_6 that functions in more than 100 enzymatic reactions, many of which involve amino acid metabolism.

Vitamin B_6, also known as **pyridoxine**, comprises a group of compounds including pyridoxal, pyridoxine, and pyridoxamine. All three forms can be converted into the active coenzyme form, **pyridoxal phosphate** (see online Appendix K). Pyridoxal phosphate is needed for the activity of more than 100 enzymes involved in the metabolism of carbohydrate, fat, and protein. It is a coenzyme for transamination reactions that synthesize nonessential amino acids, for deamination reactions needed for amino acid breakdown, and for the synthesis of neurotransmitters from amino acids (Figure 8.17). Pyridoxal phosphate is also a coenzyme needed to synthesize the conditionally essential amino acid cysteine from methionine and to synthesize hemoglobin, the oxygen-carrying protein in red blood cells. Pyridoxal phosphate is important for the immune system because it is needed to form white blood cells. It is also needed for the conversion of tryptophan to niacin, the metabolism of glycogen, and the synthesis of the lipids that are part of the myelin coating on nerves (Figure 8.18).

Vitamin B_6 Deficiency

anemia A condition in which the oxygen-carrying capacity of the blood is decreased by a reduced number of red blood cells or a reduced amount of hemoglobin in the cells.

A vitamin B_6 deficiency syndrome was defined in 1954 when an infant formula was overheated in the manufacturing process, destroying the vitamin B_6. The infants who consumed only this formula developed abdominal distress, convulsions, and other neurological symptoms.[13] The neurological symptoms associated with vitamin B_6 deficiency include depression, headaches, confusion, numbness and tingling in the extremities, and seizures. These may be related to the role of vitamin B_6 in neurotransmitter synthesis and myelin formation. **Anemia** also occurs when vitamin B_6 is deficient due to impaired hemoglobin synthesis; red blood cells are small (microcytic) and pale due to the lack of hemoglobin. Other deficiency symptoms such as poor growth, skin lesions, and decreased antibody formation may occur because vitamin B_6 is important in

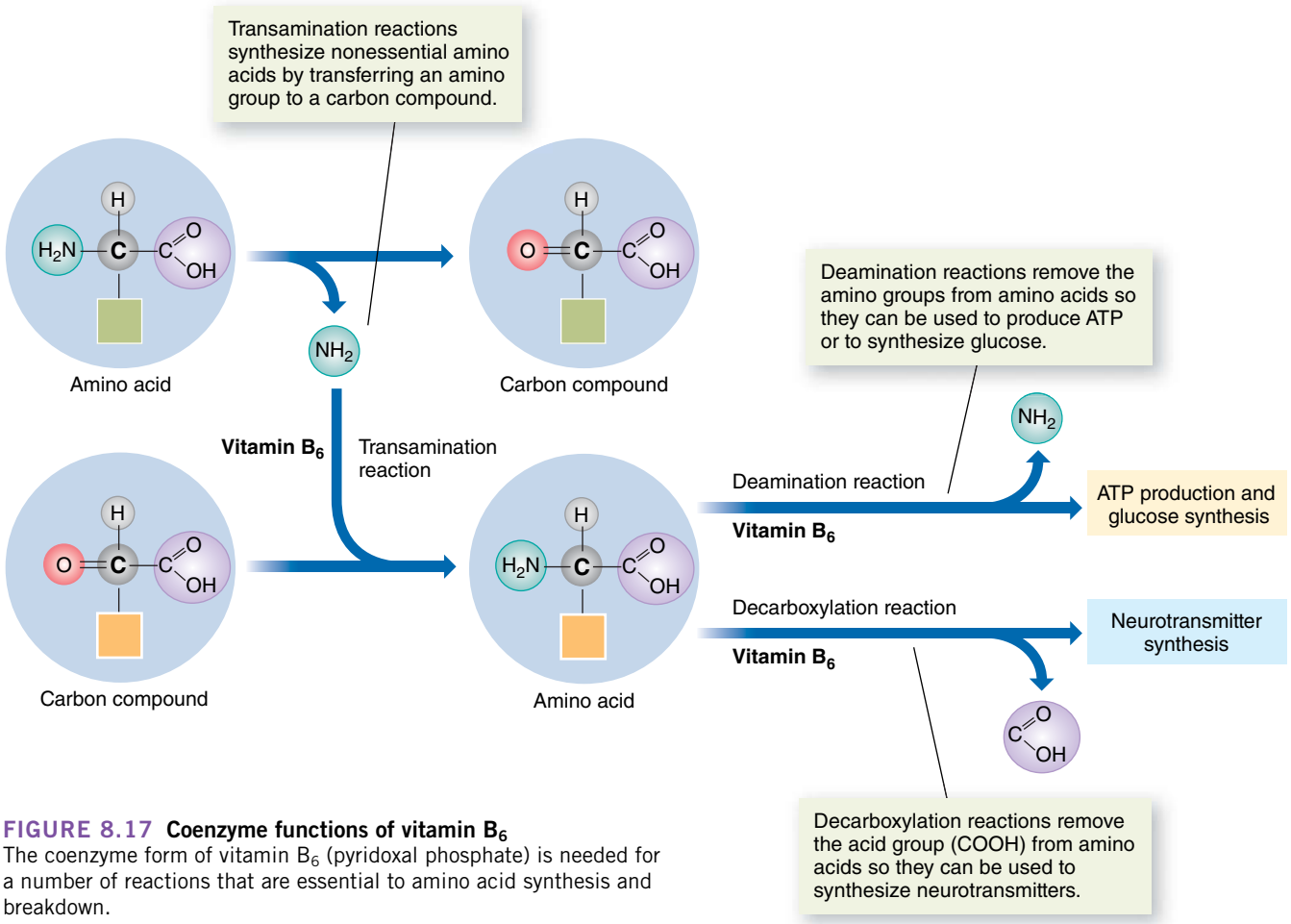


FIGURE 8.17 Coenzyme functions of vitamin B_6
The coenzyme form of vitamin B_6 (pyridoxal phosphate) is needed for a number of reactions that are essential to amino acid synthesis and breakdown.

protein and energy metabolism. Since vitamin B_6 is needed for amino acid metabolism, the onset of a deficiency can be hastened by a diet that is low in vitamin B_6 but high in protein.

Vitamin B_6 status in the body can be affected by a number of drugs, including alcohol and oral contraceptives. Alcohol decreases the formation of the active coenzyme pyridoxal phosphate and makes it more susceptible to breakdown.[5] Oral contraceptive use has been associated with low blood levels of pyridoxal phosphate.[14] Despite this, vitamin B_6 supplements are not routinely recommended for women taking oral contraceptives.

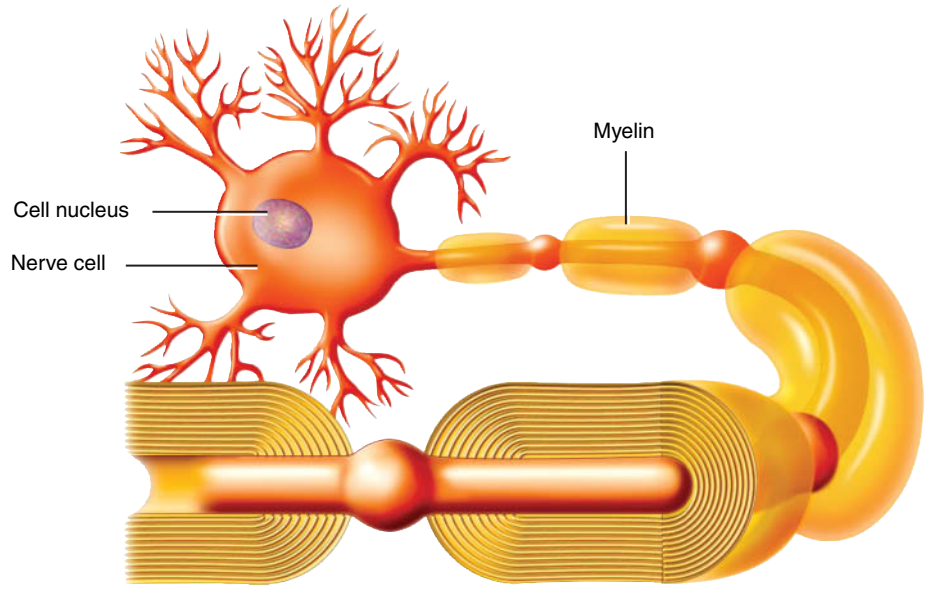


FIGURE 8.18
B vitamins and nerve function
Both vitamin B_6 and vitamin B_{12} (discussed later) are needed to synthesize and maintain the myelin coating on nerve cells. Myelin is essential for normal nerve transmission.

How Vitamin B_6 Status Is Related to Cardiovascular Disease

It has been hypothesized that vitamin B_6 affects the risk of cardiovascular disease through its role in the breakdown of the amino acid homocysteine, an intermediate in methionine metabolism (Figure 8.19). Individuals with homocystinuria, a rare genetic disorder that causes extremely high blood levels of homocysteine, develop atherosclerosis at an early age. Large doses of vitamin B_6 (100 to 1000 mg/day) have been successfully used to reduce elevated homocysteine levels and the risk of atherosclerosis in patients with one form of this disease, but these doses are not recommended for the general public.

Homocysteine is believed to increase the risk of cardiovascular disease through its effect on the structure and function of blood vessels.[15] Even mild elevations in the blood homocysteine level have been shown to increase the risk of cardiovascular disease. Elevations in homocysteine may be caused by genetic variation or a deficiency of vitamin B_6, vitamin B_{12}, or folate (the latter two are also involved in homocysteine metabolism) (see Figure 8.19). Supplements of all three of these vitamins have been used to reduce homocysteine levels in individuals with mild homocysteine elevation, but supplementation has failed to significantly reduce overall cardiovascular risk.[16] At this time, the DRI panel believes that it is premature to conclude that increased intakes of vitamin B_6, vitamin B_{12}, or folate could decrease the risk of cardiovascular disease.[5]

Recommended Vitamin B_6 Intake

The RDA for vitamin B_6 is 1.3 mg/day for both adult men and women 19 to 50 years of age.[5] This is the amount needed to maintain adequate blood concentrations of the active coenzyme pyridoxal phosphate. In adults 51 years and older, the RDA is increased to 1.7 mg/day in men and 1.5 mg/day in women to maintain normal blood levels of pyridoxal phosphate. A 3-oz (85-g) serving of chicken, fish, or pork or half a baked potato provides about a quarter of the RDA for an average adult; a banana provides about a third.

The RDA for vitamin B_6 is increased during pregnancy to provide for metabolic needs and growth of the mother and fetus. Because the vitamin B_6 concentration in breast milk is dependent on the mother's intake, the RDA is increased during lactation to ensure adequate levels are supplied to the infant. An AI for infants has been established based on the vitamin B_6 content of human milk (see inside cover).[5]

Vitamin B_6 Toxicity and Supplements

No adverse effects have been associated with high intakes of vitamin B_6 from foods, but large doses found in supplements can cause serious toxicity symptoms. This was first recognized in

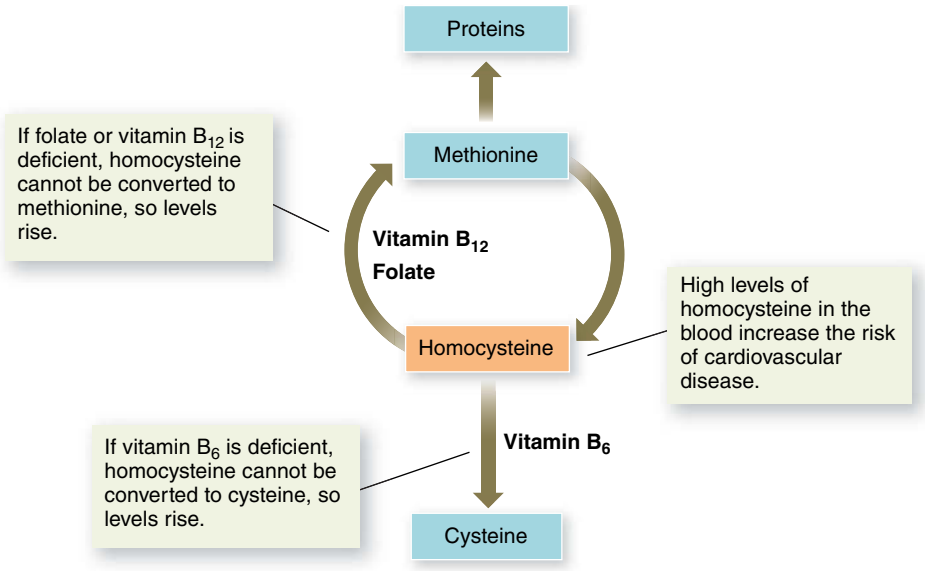


FIGURE 8.19
B vitamins and the risk of cardiovascular disease
Vitamin B_6, folate, and vitamin B_{12} are required in the metabolism of homocysteine. Without adequate amounts of these B vitamins, homocysteine levels rise and increase the risk of cardiovascular disease.

the 1980s when severe nerve impairment was reported in individuals taking 2 to 6 g of supplemental pyridoxine per day.[16] Symptoms were serious enough in some subjects that they were unable to walk. These symptoms improved when the pyridoxine supplements were stopped. To avoid toxicity when taking supplements containing vitamin B_6, it is important that intake not exceed the UL of 100 mg/day from food and supplements.[5] The UL is based on an amount that will not cause nerve damage in the majority of healthy people. Since high-dose supplements of vitamin B_6 containing 100 mg per dose (5000% of the Daily Value) are available over the counter, it is easy to obtain a dose that exceeds the UL.

Despite the potential for toxicity, people take vitamin B_6 supplements to treat carpal tunnel syndrome, reduce the symptoms of premenstrual syndrome, and strengthen immune function. Some of the marketing claims are founded in science but are often exaggerated to sell products (see Table 8.2).

Can Vitamin B_6 Alleviate Carpal Tunnel Syndrome? Vitamin B_6 supplements have been suggested to be useful in treating carpal tunnel syndrome, in which pressure on the nerves in the hand causes pain and weakness. In a clinical trial, patients with mild to moderate carpal tunnel syndrome who received 120 mg/day of vitamin B_6 for three months showed significant improvement in their clinical symptoms compared to a control group that did not receive the supplement.[17] Further investigation is needed to determine the effect of different doses of vitamin B_6.

Does Vitamin B_6 Prevent Premenstrual Syndrome (PMS)? PMS is a collection of physical and emotional symptoms that some women experience prior to menstruation. It causes mood swings, food cravings, bloating, tension, depression, headaches, acne, breast tenderness, anxiety, temper outbursts, and over 100 other symptoms. The proposed connection between these symptoms and vitamin B_6 is the fact that the vitamin is needed for the synthesis of the neurotransmitters serotonin and dopamine. Insufficient vitamin B_6 has been suggested to reduce levels of these neurotransmitters and cause the anxiety, irritability, and depression associated with PMS. A number of studies have found daily vitamin B_6 supplementation to significantly reduce PMS symptoms such as moodiness, irritability, forgetfulness, bloating, and, anxiety.[18] More research is needed to confirm that vitamin B_6 supplements are safe and effective for treating PMS.

Will Vitamin B_6 Boost Immunity? Immune function can be impaired by a deficiency of any nutrient that hinders cell growth and division. Therefore, one of the most common claims for vitamin supplements in general is that they improve immune function. Vitamin B_6 is no exception, and there are data to support the claim. Vitamin B_6 supplements have been found to improve immune function in older adults.[5] However, since elderly individuals frequently have low intakes of vitamin B_6, it is unclear whether the beneficial effects of supplements are due to an improvement in vitamin B_6 status or immune system stimulation.

8.8 Folate (Folic Acid)

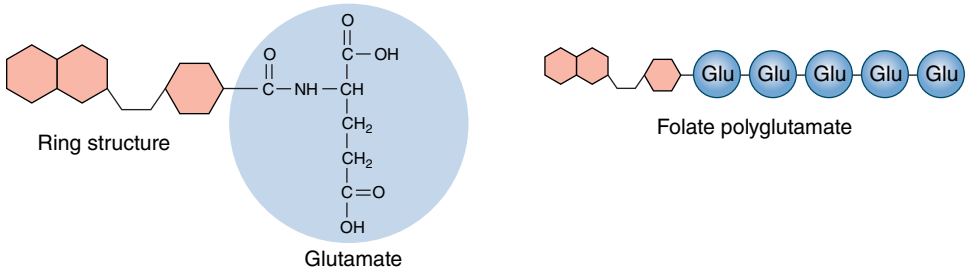
LEARNING OBJECTIVES

- Compare the bioavailability of the folate occurring naturally in food to that found in fortified foods and supplements.
- Explain how folate deficiency causes anemia.
- Discuss why supplemental folic acid is recommended for women of childbearing age.

It has been known for over 100 years that anemia often occurs during pregnancy. In 1937, a pregnant woman with anemia was successfully treated with a yeast preparation named Wills Factor (after Dr. Lucy Wills, who treated this patient). The Wills Factor was later isolated from spinach and named folate, after the Latin word for *foliage*. **Folate** and **folacin** are general terms

folate and **folacin** General terms for the many forms of this B vitamin.

FIGURE 8.20 Structure of folate



A. Folic acid, or folate monoglutamate, is the form of folate that has only one molecule of the amino acid glutamate in its structure. It is easily absorbed and is the form found in fortified foods and supplements.

B. Folate polyglutamate is the form of folate found naturally in foods; it includes many glutamate molecules (Glu) attached to form a chain. All but one glutamate must be removed before the folate can be absorbed.

folic acid The monoglutamate form of folate, which is used in fortified foods and supplements.

for compounds that have chemical structures and nutritional properties similar to those of **folic acid** (Figure 8.20). The chemical name for folate is pteroylglutamic acid.

Folate in the Diet and the Digestive Tract

Excellent dietary sources of folate include liver, yeast, asparagus, oranges, legumes, and fortified grain products. Fair sources include vegetables such as corn, snap beans, mustard greens, and broccoli, as well as some nuts and seeds. Small amounts are found in meats, cheese, and milk (Figure 8.21). Most folate found naturally in food contains a string of glutamate molecules (see Figure 8.20). Glutamate is an amino acid, and folate bound to many glutamates is referred to as *folate polyglutamate*. Before this form can be absorbed, enzymes in

THINK CRITICALLY

Which of the foods shown in the graph are fortified with folic acid?

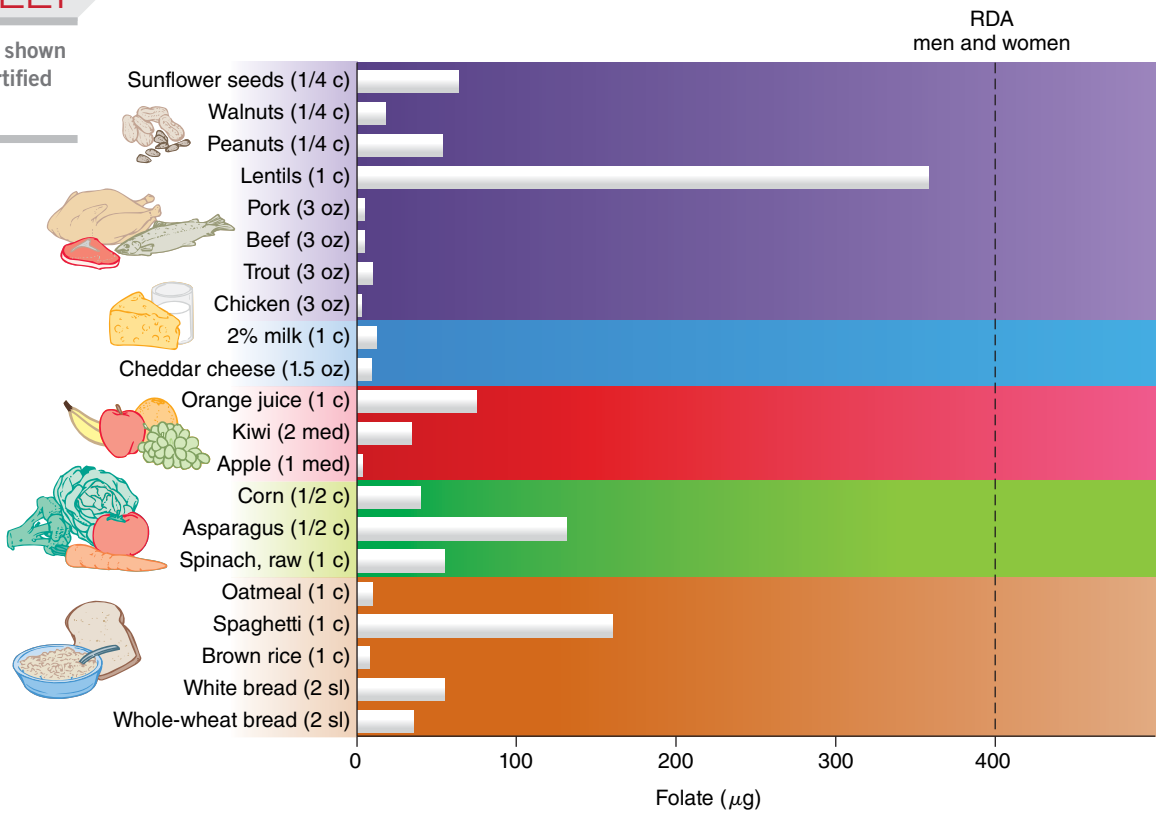


FIGURE 8.21 Folate content of MyPlate food groups
The RDA for folate (dashed line) can be met by consuming legumes, fortified foods, and fruits and vegetables.

the microvilli of the small intestine must remove all but one of the glutamate molecules to yield folic acid, the monoglutamate form. It is estimated that about 50% of the folate in food is absorbed.[5] Folic acid rarely occurs naturally in food but is used in supplements and fortified foods. It is more easily absorbed because it does not require the enzymatic removal of a string of glutamate molecules. The bioavailability of the synthetic folic acid added to grain products and used in supplements is about twice that of the folate naturally found in food. Since 1998, enriched grain products, including breads, flours, corn meal, pasta, grits, and rice, have been fortified with folic acid.

How Folate Functions in the Body

Metabolism

A number of different active coenzyme forms of folate are involved in reactions that transfer chemical groups containing a single carbon atom. Folate coenzymes are needed for the synthesis of DNA and the metabolism of some amino acids. Before a cell divides, its DNA must replicate. Therefore, the role of folate in DNA synthesis makes it particularly important in tissues where cells are rapidly dividing such as bone marrow, where red blood cells are made, intestines, and skin and during periods of rapid growth, such as early in embryonic life.

Folate Deficiency

A deficiency of folate leads to a drop in blood folate levels and a rise in blood homocysteine followed by changes that affect rapidly dividing cells. Deficiency symptoms include anemia, poor growth, problems in nerve function, diarrhea, and inflammation of the tongue. Low folate intake in early pregnancy is associated with an increased risk of **neural tube defects**. Low folate status may also increase the risk of developing heart disease and certain types of cancer. Groups at risk of folate deficiency include pregnant women and premature infants because of their rapid rate of cell division and growth, older adults because of their limited intake of foods high in folate, alcoholics because alcohol inhibits folate absorption, and tobacco smokers because smoke inactivates folate in the cells lining the lungs.[5]

neural tube defects Birth defects caused by abnormal development of the neural tube, the portion of the embryo that gives rise to the central nervous system.

macrocytes Larger-than-normal mature red blood cells that have a shortened life span.

macrocytic anemia A reduction in the blood's hemoglobin content and hence capacity to carry oxygen that is characterized by abnormally large red blood cells.

Why Folate Deficiency Causes Anemia Folate is needed for cells to divide. When folate is deficient, cells in the bone marrow that develop into red blood cells cannot replicate their DNA and so cannot divide. Instead, they just grow bigger. These large immature cells are known as *megaloblasts* and can be converted into large red blood cells called **macrocytes**. The result is that fewer mature red blood cells are produced and the oxygen-carrying capacity of the blood is reduced. This condition is called **macrocytic anemia** (Figure 8.22).

How Folate Is Related to the Risk of Neural Tube Defects Neural tube defects are not true folate-deficiency symptoms because not every pregnant woman with inadequate folate levels will bear a child with a neural tube defect. Instead, neural tube defects are probably due to a combination of factors that include low folate levels and a genetic predisposition. The exact role

LIFE CYCLE

THINK CRITICALLY

Why does the inability to replicate DNA prevent cells from dividing?

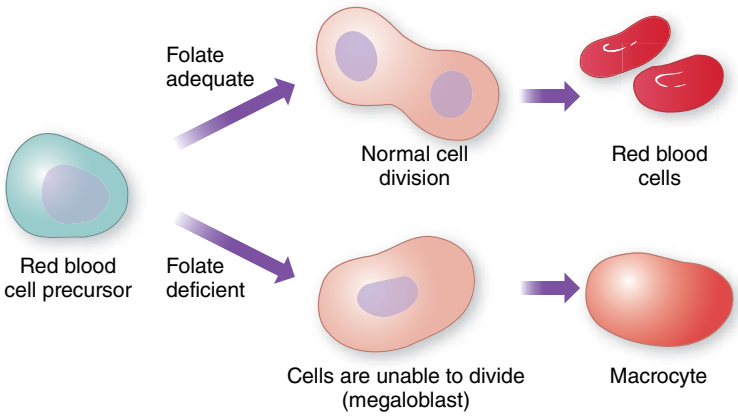


FIGURE 8.22 Folate deficiency and macrocytic anemia
Folate is needed for DNA replication. Without folate, red blood cell precursors are unable to divide, resulting in the formation of abnormally large red blood cells called macrocytes.

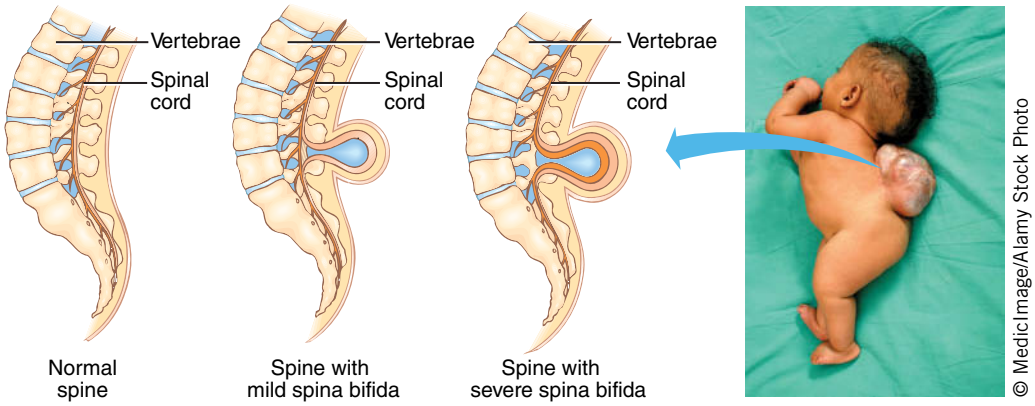


FIGURE 8.23 Spina bifida
If a lower portion of the neural tube does not close normally, spina bifida (shown here) results.

of folate in neural tube development is not known, but it is necessary for a critical step called neural tube closure. When neural tube closure does not occur normally, portions of the brain or spinal cord are not fully developed or adequately protected. **Anencephaly** is a neural tube defect that affects the brain. It occurs when the head end of the neural tube does not close properly, resulting in incomplete formation of the brain. Babies with anencephaly are usually blind and deaf and die soon after birth. **Spina bifida** is a neural tube defect that affects the spine. It can cause nerve damage that leads to varying degrees of paralysis of the lower limbs and in some cases learning disabilities (Figure 8.23).

anencephaly A birth defect due to failure of the neural tube to close; it results in the absence of a major portion of the brain, skull, and scalp.

spina bifida A type of neural tube defect resulting from the incorrect development of the spinal cord that can leave the spinal cord exposed.

Neural tube closure is complete by 28 days after conception; therefore, folate status should be adequate even before a pregnancy begins to ensure an adequate supply during early development (see Chapter 14). Studies in which supplemental folic acid was given to women before and during early pregnancy showed that 360 to 800 μg/day of synthetic folic acid in addition to food folate was associated with a reduced incidence of neural tube defects.[5] Because it is not known whether a diet naturally rich in folate offers the same protection as folic acid, supplemental folic acid from supplements or fortified foods is recommended. To be effective, folate status must be adequate before most women are aware that they are pregnant, and, therefore, supplemental folic acid is recommended for all women of childbearing age. To help ensure adequate folate intake in women of childbearing age, in 1998 the FDA mandated that folic acid be added to all enriched grains and cereal products. Since then, the incidence of neural tube defects in the United States has decreased by about 30%, and reductions ranging from 19 to 55% have been observed in other countries where folic acid fortification has been introduced (see Chapter 14, *Science Applied: Folate: Reducing Birth Defects through Fortification*).[19,20]

How Folate Is Related to the Risk of Cardiovascular Disease Low intakes of folate have been associated with an increased risk of cardiovascular disease. Its effect on cardiovascular disease is related to its role in the metabolism of the amino acid homocysteine (see Figure 8.19). Folate is needed to convert homocysteine to methionine. When folate is deficient, homocysteine levels rise because less is converted to methionine. The elevated homocysteine levels then increase the risk of cardiovascular disease (see discussion above of vitamin B_6 and cardiovascular disease). Although supplementation with folic acid and vitamins B_6 and B_{12} lowers homocysteine levels, it has not been shown to reduce the risk of cardiovascular disease.[16]

How Folate Is Related to Cancer The relationship between folate and cancer is complicated. Folate is needed for cells to replicate normally. When levels of folate in the body are low, changes in DNA that contribute to the development of cancer are more likely. Epidemiological studies show an inverse association between folate intake and the incidence of a variety of cancers, including breast, colorectal, esophageal, and pancreatic.[21–23] Despite this, folic acid supplementation has not been found to reduce the overall risk of cancer and may increase the risk of some cancers.[24] Evidence from clinical trials and laboratory and animal studies suggests that folate might play dual roles in cancer risk depending on the dose and when it is taken. Modest doses of supplemental folic acid taken before precancerous cells develop might suppress the

development of cancer, whereas high doses taken after precancerous cells have formed might promote cancer development and progression by supporting the rapid DNA replication that occurs in cancerous cells.[25]

Recommended Folate Intake

The RDA for folate is set at 400 μg **dietary folate equivalents (DFEs)** per day for adult men and women. One DFE is equal to 1 μg of food folate, 0.6 μg of synthetic folic acid from fortified food or supplements consumed with food, or 0.5 μg of synthetic folic acid consumed on an empty stomach. To reduce the risk of neural tube defects, a special recommendation is made for women capable of becoming pregnant.[5] A daily intake of 400 μg of synthetic folic acid from fortified foods and/or supplements is recommended in addition to the food folate consumed in a varied diet. Therefore, the total folate intake of this group should exceed the RDA (see **Critical Thinking: Meeting Folate Recommendations**).

dietary folate equivalents (DFEs) The unit used to express folate recommendations. One DFE is equivalent to 1 μg of folate naturally occurring in food, 0.6 μg of synthetic folic acid from fortified food or supplements consumed with food, or 0.5 μg of synthetic folic acid consumed on an empty stomach.

The RDA for folate during pregnancy is increased to 600 μg/day to provide for the increase in cell division. Although this level can be met by a carefully selected diet, folate is typically supplemented during pregnancy. The RDA is increased during lactation to account for folate secretion in milk. Needs per unit of body weight are higher for infants and children than for adults because of their rapid growth (see inside cover). Human and cow's milk provide enough folate to meet infant needs, but goat's milk does not. Infants and children given goat milk may not receive adequate folate unless it is provided from other sources.

Meeting Folate Needs

Women of childbearing age can meet folate recommendations by taking a multivitamin containing folic acid or by including fortified foods in their diet. To get the recommended 400 μg DFE of synthetic folic acid from fortified foods would require eating about one to four servings of fortified breakfast cereal or four to six servings of other fortified grain products each day. If it is not possible to meet recommendations from fortified foods, supplements should be used.

The Daily Values on food labels and values in some food composition tables are listed as micrograms of total folate, not as micrograms of DFE. DFEs correct for differences in the bioavailability of different forms of folate. For foods that are natural sources of folate, the folate content can be determined by multiplying the Daily Value (400 μg) by the % Daily Value listed on the label (see Chapter 11, *Off the Label: How Much Calcium Is in Your Yogurt?*). So, to calculate the folate in a package of frozen spinach that provides 25% of the Daily Value, multiply 400 μg folate × 0.25 = 100 μg DFE. In foods fortified with folic acid, the amount of folate indicated by the % Daily Value must be multiplied by 1.7 to account for the greater bioavailability of folic acid (Table 8.3).

TABLE 8.3 Calculating Dietary Folate Equivalents in Fortified Foods

The folate listed on labels of fortified foods is primarily folic acid, which is more available than natural forms of folate. To compare the folate content of these foods to recommendations, the amount of folic acid must be converted to dietary folate equivalents, expressed as μg DEF. This calculation assumes that all of the folate in these foods is from added folic acid.

Determine the amount of folic acid in the fortified food:

- Multiply the Daily Value for folate by the % Daily Values listed on the label.
  Daily Value is 400 μg.

Convert the μg folic acid into μg DFE:

- Multiply the μg folic acid by 1.7.
  Folic acid added to a food in fortification provides 1.7 times more available folate per microgram than folate naturally present in foods.

For example:

- A serving of English muffins provides 6% of the Daily Value for folate:
  To find the μg folic acid: 400 μg × 0.06 = 24 μg folic acid
  To convert to μg DFE: 24 μg folic acid × 1.7 = 40 μg DFE

CRITICAL THINKING

Meeting Folate Recommendations

© Lynn Bendickson/iStockphoto

Mercedes would like to have a baby. At her annual physical, her physician advises her that women who are capable of becoming pregnant should consume 400 μg of folic acid from fortified foods or supplements each day in addition to the folate found in a varied diet. Mercedes records her food intake for a day to estimate her folate intake.

▼

Which five foods in her diet are highest in folate? Of these, which are fortified with folic acid?

FOOD	SERVING	TOTAL FOLATE (μg)
Breakfast		
Oatmeal, regular	1 cup	2
Milk	1 cup	12
Banana	1 medium	22
Orange juice	1 cup	75
Coffee	1 cup	0
Lunch		
Hamburger	3 oz	11
Hamburger bun	1	32
French fries	20 pieces	24
Coke	12 oz	0
Apple	1 medium	4
Dinner		
Chicken	3 oz	4
Refried beans	½ cup	106
White rice	1 cup	80
Flour tortilla	1	60
Salad	1 cup	64
Salad dressing	1 T	1
Milk	1 cup	12
White cake	1 piece	32
Total		**541**

▼

How much folic acid does Mercedes consume from fortified foods? Does this meet the recommendation?

CRITICAL THINKING QUESTIONS

- **If Mercedes replaced all of her refined grains with whole grains, how would her folate intake change?**
- **Why is folate a concern for women planning a pregnancy?**
- **Would you recommend that Mercedes take a folic acid supplement? Why or why not?**

iProfile Use iProfile to find out how much folate is in the folate-fortified grain products you consume each day.

Folate Toxicity

Although there is no known folate toxicity, a high intake may mask the early symptoms of vitamin B_{12} deficiency, allowing it to go untreated and resulting in irreversible nerve damage. This is discussed below. The UL for folic acid for adults is set at 1000 μg/day from supplements and/or fortified foods. This value was determined based on the progression of neurological symptoms seen in patients who are deficient in vitamin B_{12} and taking folic acid supplements.

8.9 Vitamin B_{12}

LEARNING OBJECTIVES

- Name foods that are good sources and poor sources of vitamin B_{12}.
- List the steps involved in vitamin B_{12} absorption.
- Compare the functions of folate and vitamin B_{12}.

In 1820, when it was first described, a diagnosis of **pernicious anemia** was a death sentence. It did not respond to iron supplements, but in the 1920s, researchers George Minot and William Murphy pursued their belief that pernicious anemia could be cured by something else in the diet. They discovered that they could restore patients' health by feeding them about 4 to 8 oz of slightly cooked liver at every meal. Today we know that pernicious anemia is caused by an inability to absorb sufficient vitamin B_{12} and that eating liver cured the disease because liver is a concentrated source of vitamin B_{12}. Pernicious anemia is now treated with injections or megadoses of vitamin B_{12} rather than with plates full of liver.

pernicious anemia A macrocytic anemia resulting from vitamin B_{12} deficiency that occurs when dietary vitamin B_{12} cannot be absorbed due to a lack of intrinsic factor.

Vitamin B_{12} in the Diet

Vitamin B_{12} is found almost exclusively in animal products (Figure 8.24). It can be made by bacteria, fungi, and algae but not by plants and animals. It accumulates in animal tissue from the diet or from synthesis by the bacterial microbiota. The human microbiota produces vitamin B_{12}

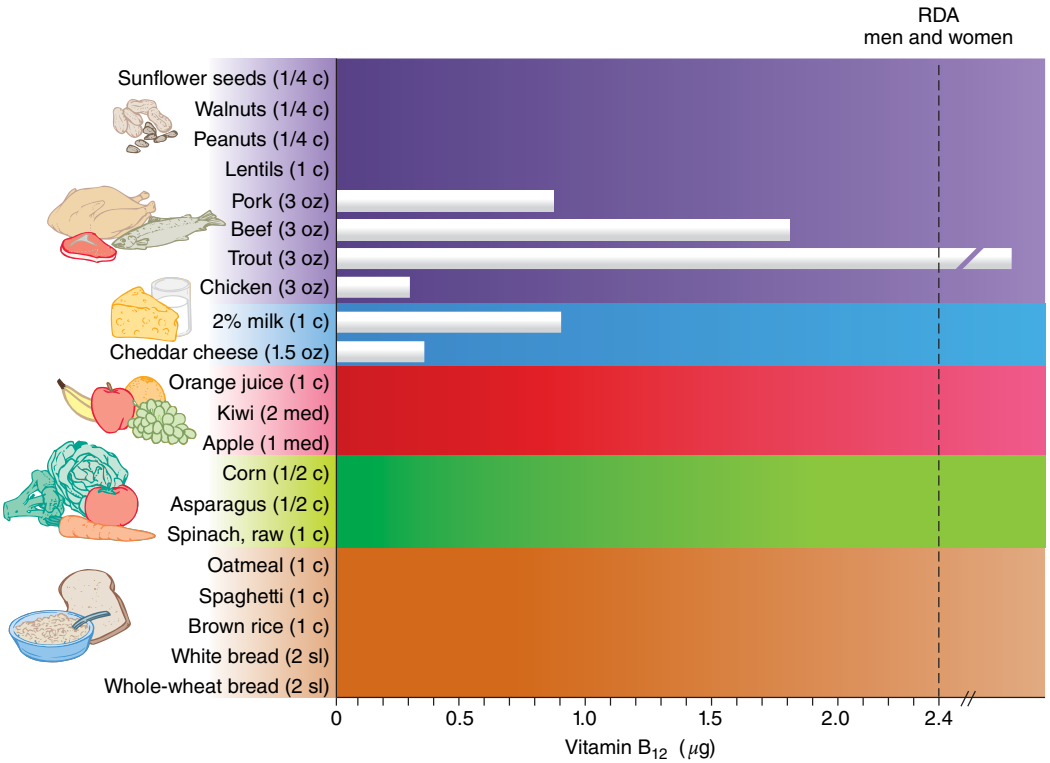


FIGURE 8.24 Vitamin B_{12} content of MyPlate food groups
Animal products provide vitamin B_{12}, but plant products do not; the dashed line represents the RDA for adult men and women.

in the colon, but it cannot be absorbed. Vitamin B_{12} is not found in plant products unless they have been contaminated with bacteria, soil, insects, or other sources of vitamin B_{12} or have been fortified with it. Diets that do not include animal products must include supplements or foods fortified with vitamin B_{12} in order to meet needs.[26]

Vitamin B_{12} in the Digestive Tract

intrinsic factor A protein produced in the stomach that is needed for the absorption of adequate amounts of vitamin B_{12}.

parietal cells Large cells in the stomach lining that produce and secrete intrinsic factor and hydrochloric acid.

The vitamin B_{12} naturally present in food is bound to proteins and must be released before it can be absorbed. In the stomach, acid and the protein-digesting enzyme pepsin unfold proteins and begin their digestion, releasing the vitamin B_{12}. If stomach acid is low, the vitamin cannot be released from food proteins and absorption is reduced. In the small intestine, vitamin B_{12} binds to **intrinsic factor**. Intrinsic factor is a protein secreted by the **parietal cells** in the gastric glands lining the stomach. The intrinsic factor–vitamin B_{12} complex binds to receptor proteins in the ileum—the last 11 feet of the small intestine—allowing the vitamin to be absorbed (Figure 8.25). Only a small amount of vitamin B_{12} can be absorbed when intrinsic factor is absent. Vitamin B_{12} absorption is also reduced when pancreatic secretions are insufficient.

Vitamin B_{12} is secreted in bile, but most of this is reabsorbed rather than being lost in the feces. Because of this efficient recycling, it can take many years of a deficient diet before the symptoms of vitamin B_{12} deficiency appear.

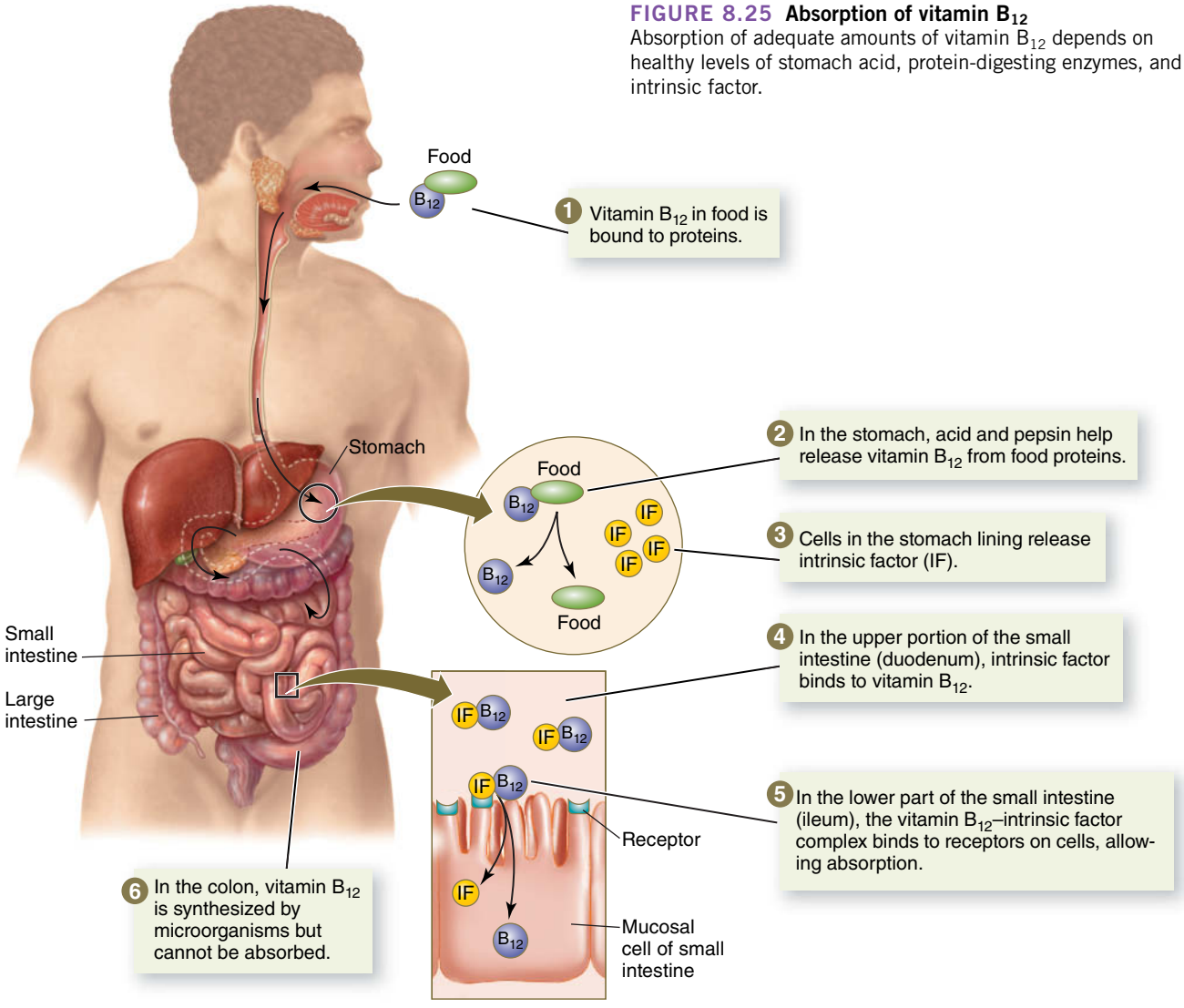


FIGURE 8.25 Absorption of vitamin B_{12}
Absorption of adequate amounts of vitamin B_{12} depends on healthy levels of stomach acid, protein-digesting enzymes, and intrinsic factor.

How Vitamin B_{12} Functions in the Body

Metabolism

Vitamin B_{12}, also known as **cobalamin**, can be converted into either of two active cobalamin coenzyme forms, methylcobalamin and adenosylcobalamin (see online Appendix K). These coenzymes function in two important metabolic reactions. One rearranges carbon atoms so that the breakdown products of some fatty acids and amino acids can enter the citric acid cycle and be used to provide energy. This reaction is necessary for the maintenance of healthy myelin, which insulates nerves and is essential for normal nerve transmission (see Figure 8.18). A second vitamin B_{12}–dependent reaction synthesizes the amino acid methionine from homocysteine. This reaction also requires folate (see Figure 8.19).

cobalamin The chemical term for a cobalt-containing compound commonly known as vitamin B_{12}.

Vitamin B_{12} Deficiency

The body stores and reuses vitamin B_{12} more efficiently than it does most other water-soluble vitamins, so deficiency is typically caused by poor absorption rather than by low intake alone. Symptoms of vitamin B_{12} deficiency include an increase in blood homocysteine levels and macrocytic anemia that is indistinguishable from that seen in folate deficiency. This anemia occurs because vitamin B_{12} is needed to convert folate into the form that is active for DNA synthesis (**Figure 8.26**). Lack of vitamin B_{12} causes a secondary folate deficiency and consequently macrocytic anemia. Vitamin B_{12} deficiency also interferes with the maintenance of the myelin that coats the nerves, spinal cord, and brain. Myelin degeneration causes neurological symptoms, which include numbness and tingling, abnormalities in gait, memory loss, and disorientation. If not treated, this eventually causes paralysis and death.

Blatant deficiencies of vitamin B_{12} are rare because the body stores and reuses it efficiently. However, marginal vitamin B_{12} status is of public health concern, particularly for older adults and vegetarians who consume no animal products. Because of the efficient recycling of vitamin B_{12}, it can take many years of a deficient diet before the symptoms of deficiency appear. However, when absorption is impaired, neither dietary vitamin B_{12} nor the vitamin B_{12} secreted in the bile is absorbed, so deficiency symptoms appear more rapidly. This occurs both in individuals with pernicious anemia and in those with **atrophic gastritis**.

atrophic gastritis An inflammation of the stomach lining that results in reduced secretion of stomach acid and bacterial overgrowth.

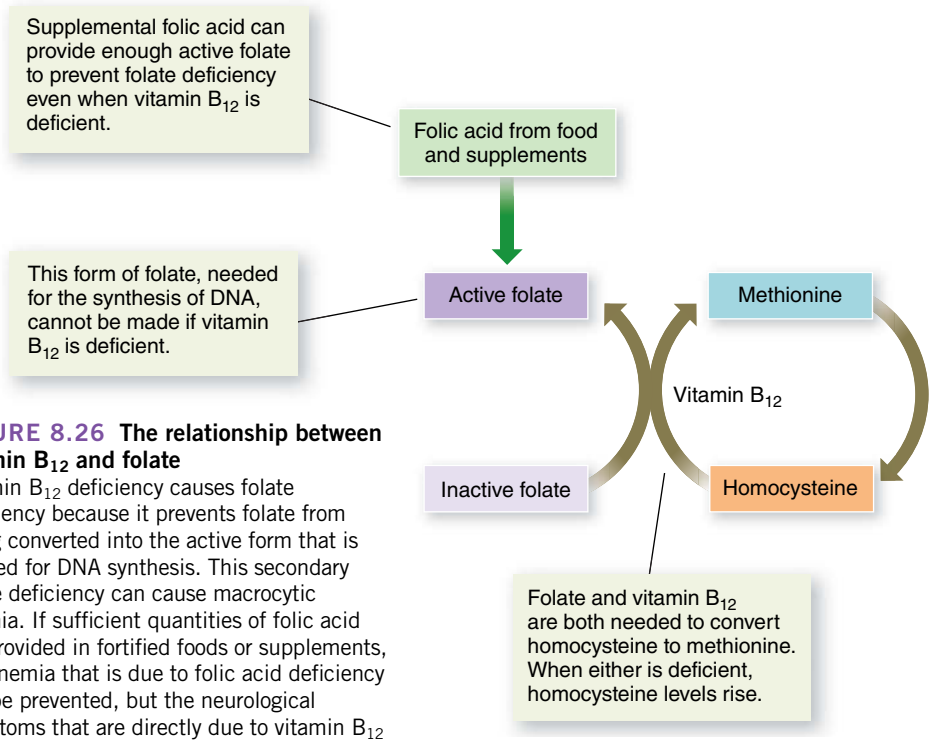


FIGURE 8.26 The relationship between vitamin B_{12} and folate
Vitamin B_{12} deficiency causes folate deficiency because it prevents folate from being converted into the active form that is needed for DNA synthesis. This secondary folate deficiency can cause macrocytic anemia. If sufficient quantities of folic acid are provided in fortified foods or supplements, the anemia that is due to folic acid deficiency can be prevented, but the neurological symptoms that are directly due to vitamin B_{12} deficiency continue to progress.

THINK CRITICALLY

If you were deficient in vitamin B_{12} but took large amounts of folic acid from supplements, would you develop macrocytic anemia? Why or why not?

Why Vitamin B_{12} Absorption Is Impaired in Pernicious Anemia Pernicious anemia is an autoimmune disease in which the parietal cells in the stomach, which produce intrinsic factor, are destroyed. Without intrinsic factor, vitamin B_{12} cannot be absorbed normally. The resulting anemia can be treated with injections of the vitamin, with a B_{12}-containing nasal gel, or with oral megadoses. The injections, which deliver vitamin B_{12} to the subcutaneous fat or muscle, and the nasal gel, which allows the vitamin to enter the bloodstream through the nasal mucosa, bypass the gastrointestinal tract and thus the need for intrinsic factor. Megadoses can treat pernicious anemia because they allow adequate amounts of vitamin B_{12} to be absorbed by passive diffusion, which does not require intrinsic factor.

How Atrophic Gastritis Causes Vitamin B_{12} Deficiency About 10 to 30% of individuals over 50 years of age are unable to absorb food-bound vitamin B_{12} normally because they have atrophic gastritis. Atrophic gastritis is an inflammation of the stomach lining that results in a reduction in stomach acid and bacterial overgrowth. When stomach acid is reduced, the enzymes that release vitamin B_{12} that is bound to food proteins cannot function properly and the bound vitamin B_{12} cannot be released and absorbed. Atrophic gastritis also causes microbial overgrowth in the intestine. These microbes reduce the amount of vitamin B_{12} that is absorbed by competing for available vitamin B_{12}. In severe cases of atrophic gastritis, the production of intrinsic factor is also reduced, further impairing vitamin B_{12} absorption. It is recommended that individuals over the age of 50 meet their RDA by consuming foods fortified with vitamin B_{12} such as breakfast cereals or soy-based products or by taking a vitamin B_{12}–containing supplement.[5] Because the vitamin B_{12} in these products is not bound to proteins, it is absorbed even when stomach acid is low.

Vegan Diets Vitamin B_{12} deficiency is also a concern among vegans since vitamin B_{12} is found only in foods of animal origin. Severe deficiency has been observed in breast-fed infants of vegan women, but marginal deficiency is a concern for all vegans if supplements or fortified foods are not included in the diet.

Why Supplemental Folic Acid Can Mask Vitamin B_{12} Deficiency If individuals with vitamin B_{12} deficiency consume enough folate, they will not develop anemia, which is an easily identified and reversible symptom of vitamin B_{12} deficiency (see Figure 8.26). Without this symptom, diagnosis can be delayed, allowing more serious and irreversible symptoms, such as nerve damage, to progress. There is a concern that the additional folic acid in the food supply from the fortification of grain products could delay the diagnosis of vitamin B_{12} deficiency. This is a particular concern in older adults because they are more likely to develop a vitamin B_{12} deficiency and therefore monitoring of vitamin B_{12} levels in the blood for those at risk is recommended.

Recommended Vitamin B_{12} Intake

The RDA for adults of all ages for vitamin B_{12} is 2.4 μg/day.[5] This is the amount needed to maintain normal red blood cell parameters and normal blood concentrations of vitamin B_{12}. Average intake in the U.S. population exceeds the RDA for both adult men and women.

The RDA for vitamin B_{12} is increased during pregnancy, even though absorption is increased. The RDA during lactation is increased to account for the amount secreted in milk. Pregnant and lactating vegans, like anyone who does not eat animal products, are advised to take a supplement or consume fortified foods to obtain the recommended intake for vitamin B_{12}.[26]

Vitamin B_{12} Toxicity and Supplements

No toxic effects have been reported with excess vitamin B_{12} intakes of up to 100 μg/day from food or supplements. Sufficient data are not available to establish a UL for vitamin B_{12}.

Supplements of vitamin B_{12} are available as cyanocobalamin in both oral and injectable forms. Because vitamin B_{12} deficiency causes anemia, supplements of the vitamin, particularly as injections, have been promoted as a pick-me-up for tired, run-down individuals. There are no proven benefits of vitamin B_{12} supplementation in individuals who are not vitamin B_{12} deficient. However, because 10 to 30% of older people may be unable to absorb naturally occurring vitamin B_{12} and because vitamin B_{12} is not found in plant foods, it is advisable for those older than 50 years and those consuming vegan diets to meet their RDA by consuming foods fortified with vitamin B_{12} or a vitamin B_{12}–containing supplement.[5]

8.10 Vitamin C

LEARNING OBJECTIVES

- List the food groups that include good sources of vitamin C and ones that are lacking in foods that provide vitamin C.
- Explain how vitamin C prevents oxidative damage.
- Relate the role of vitamin C in the body to the symptoms of scurvy.

The vitamin C deficiency disease **scurvy** has plagued armies, navies, and explorers throughout history. The reason obtaining enough vitamin C, also known as **ascorbic acid** or **ascorbate**, has been a particular problem for armies and explorers is that fresh fruits and vegetables are its main sources; these foods spoil quickly and don't transport well on long voyages. In the mid-1500s, the Indians of eastern Canada knew that an extract from white cedar needles would cure the disease. In 1594, after a voyage to the South Seas, Sir Richard Hawkins recommended that this sickness be treated by including citrus fruit in the diet. Despite this recommendation, 10,000 British sailors died of scurvy that same year. Over 100 years later, James Lind, a Scottish physician serving in the British navy, tested various agents for their effectiveness at curing scurvy and reported that two patients given citrus fruits recovered within six days (see Chapter 1, *Critical Thinking: Early Science*). However, it was another 48 years before lime or lemon juice became a requirement in the rations of the mercantile service, earning British sailors the name *limeys*. Unfortunately, the rest of the world did not heed the lesson of the limeys. In the mid-19th century, during the U.S. Civil War, scurvy was rampant.

scurvy A vitamin C deficiency disease characterized by bleeding gums, tooth loss, joint pain, bleeding into the skin and mucous membranes, and fatigue.

ascorbic acid or **ascorbate** The chemical term for vitamin C.

Vitamin C in the Diet

Citrus fruits, such as oranges, lemons, and limes, are excellent sources of vitamin C (Figure 8.27). Other fruits high in vitamin C include strawberries and cantaloupe. Vegetables in the cabbage

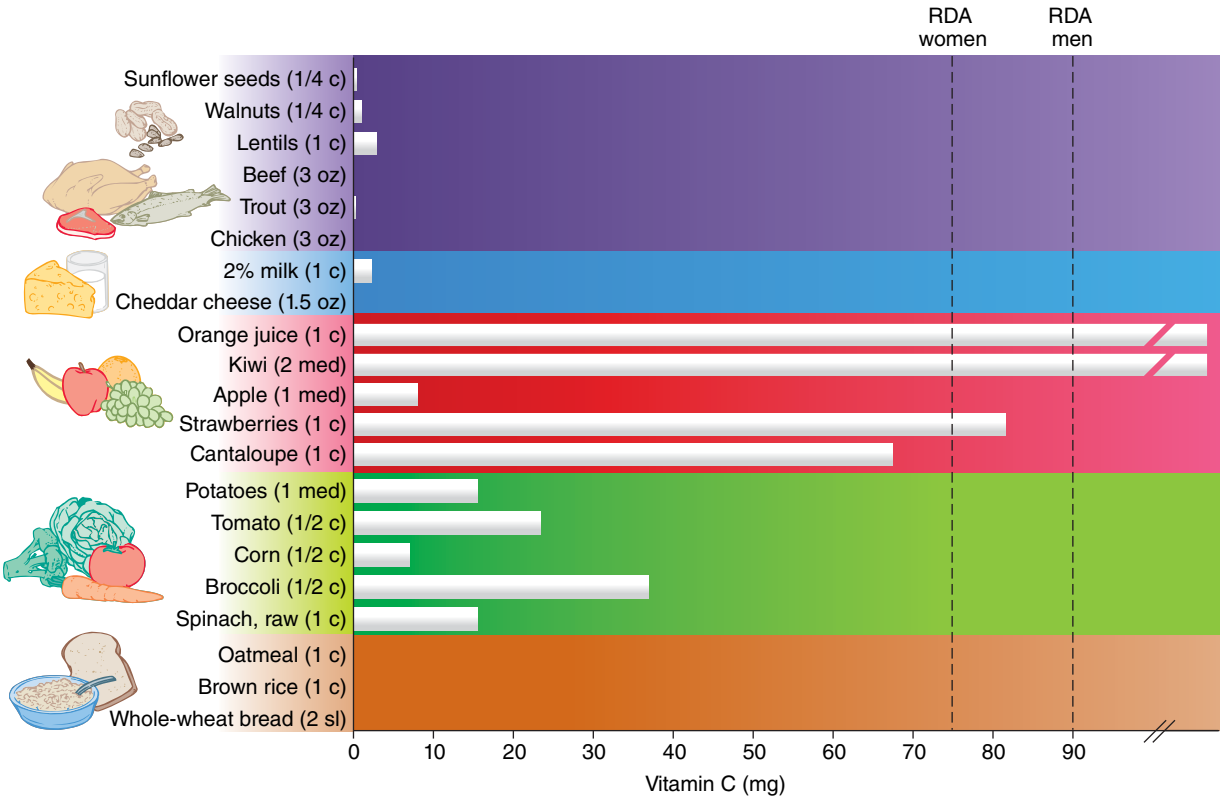


FIGURE 8.27 Vitamin C content of MyPlate food groups
Fruits and vegetables are the best sources of vitamin C; the dashed lines represent the RDAs for adult women and men.

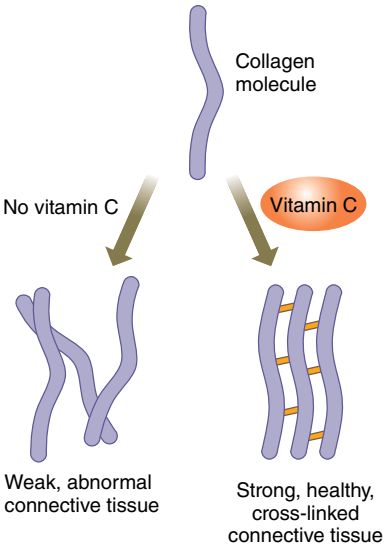


FIGURE 8.28 Role of vitamin C in collagen synthesis
Reactions requiring vitamin C are essential for the formation of bonds that hold adjacent collagen strands together and give the protein strength and stability.

family, such as broccoli, cauliflower, bok choy, and Brussels sprouts, as well as green leafy vegetables, green and red peppers, okra, tomatoes, and potatoes, are also good sources. Meat, fish, poultry, eggs, dairy products, and grains are poor sources. The amount of vitamin C in packaged foods is currently listed on food labels as a percentage of the Daily Value. This information can be used to identify packaged foods, such as frozen strawberries and orange juice, that are good sources of vitamin C. Fresh fruits and vegetables, which are the best sources of vitamin C, do not carry food labels.

Vitamin C is unstable and is destroyed by oxygen, light, and heat, so it is readily lost in cooking. This loss is accelerated by contact with copper or iron cooking utensils and by low-acid conditions.

How Vitamin C Functions in the Body

Vitamin C is a water-soluble vitamin that donates electrons in biochemical reactions, including those needed for the synthesis and maintenance of connective tissue. Because it can donate electrons, vitamin C also has a more general role as an antioxidant that, along with other antioxidants, protects the body from reactive oxygen molecules. Vitamin C also serves as a coenzyme in reactions needed for the synthesis of neurotransmitters, hormones such as the thyroid and steroid hormones, bile acids, and carnitine needed for fatty acid breakdown. It also helps maintain the immune system and aids in the absorption of iron.

collagen The major protein in connective tissue and the most abundant protein in the body.

oxidative damage Damage caused by highly reactive oxygen molecules that steal electrons from other compounds, causing changes in structure and function.

oxidative stress A condition that occurs when there are more reactive oxygen molecules than can be neutralized by available antioxidant defenses.

pro-oxidant A substance that promotes oxidative damage.

free radical An atom or group of atoms that has at least one unpaired electron and is therefore unstable and highly reactive and can cause cellular damage.

dietary antioxidant A substance in food that significantly decreases the adverse effects of reactive species on normal physiological function in humans.

Vitamin C Is Needed for Collagen Synthesis

Many of the biochemical reactions requiring vitamin C add a hydroxyl group (OH) to other molecules. Two such reactions are essential for the formation of **collagen**, the protein that forms the base of all connective tissue in the body. Vitamin C is a coenzyme needed for activity of the enzymes that add the hydroxyl groups to the amino acids proline and lysine to form hydroxyproline and hydroxylysine, respectively. These hydroxyl groups are necessary for the formation of chemical bonds that cross-link the polypeptide strands of collagen to give it strength (Figure 8.28).

Vitamin C as an Antioxidant

Vitamin C also functions as an antioxidant. Antioxidants protect against **oxidative damage**, which is damage caused by reactive oxygen molecules. **Oxidative stress** refers to an imbalance between the amounts of reactive oxygen molecules and the availability of antioxidant defenses. Oxidative stress has been related to the aging process as well as to the development of cancer and heart disease. Agents that can induce oxidative stress by causing an increase in reactive oxygen molecules, a decrease in antioxidant defenses, or an increase in oxidative damage are called **pro-oxidants**.

How Antioxidants Work

Free radicals and other reactive oxygen molecules come from environmental sources such as air pollution or cigarette smoke as well as from normal oxygen-requiring reactions inside the body. Free radicals cause damage by snatching electrons from DNA, proteins, carbohydrates, or unsaturated fatty acids. This results in changes in the structure and function of these molecules. DNA damage is hypothesized to be a major reason for the increase in cancer incidence that occurs with age. Oxidation of lipoproteins is a critical step in the development of atherosclerosis.

Antioxidants act by destroying reactive oxygen molecules before they can do damage. Some directly destroy free radicals, while others neutralize other reactive molecules, such as superoxide radicals or peroxides, before they can form free radicals. Some antioxidants are produced in the body; others are consumed in the diet. Vitamin C, vitamin E, and the mineral selenium have been classified as **dietary antioxidants** (see Chapter 12, *Debate: Antioxidant Supplements: Helpful or Harmful?*).[27]

How Vitamin C Functions as an Antioxidant

Vitamin C acts as an antioxidant in the blood and other body fluids. It can donate an electron to neutralize superoxide radicals and free radicals before they can damage lipids and DNA (Figure 8.29). Vitamin C has also

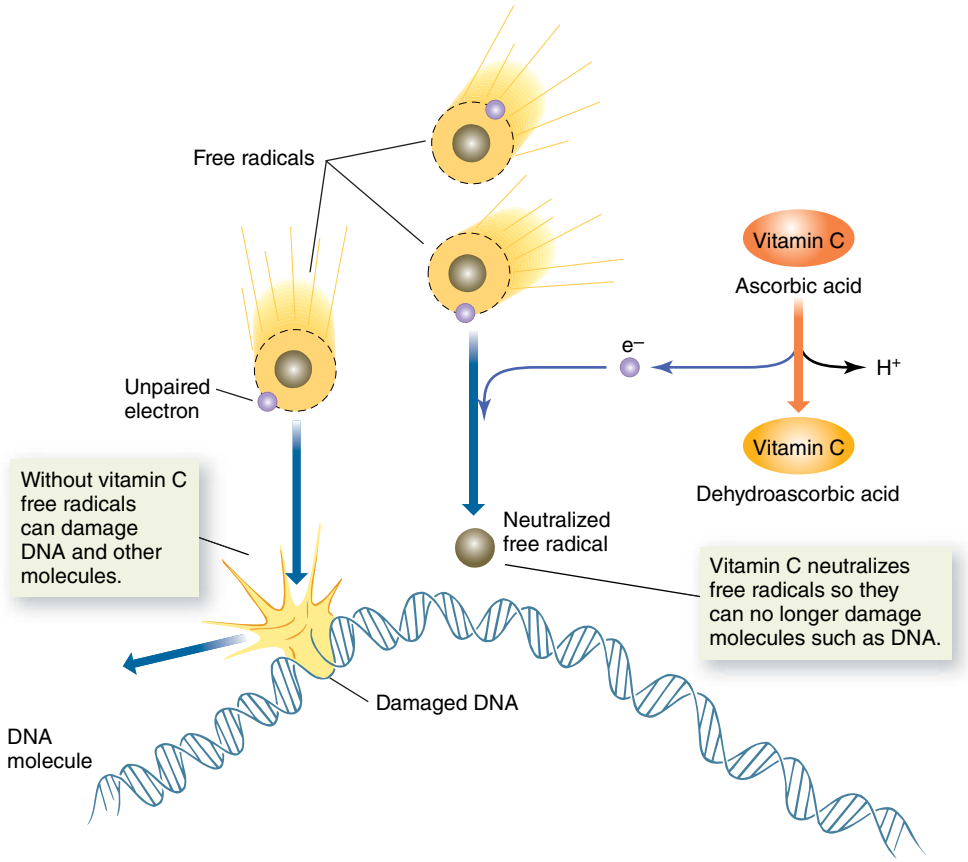


FIGURE 8.29
Antioxidant role of vitamin C
Vitamin C functions as an antioxidant by donating electrons to neutralize free radicals so that they are no longer damaging. When ascorbic acid donates an electron, it also loses a hydrogen ion to form a molecule of dehydroascorbic acid. This reaction is reversible and vitamin C can be restored when electrons and hydrogens are provided by other antioxidants such as glutathione.

been shown to scavenge reactive oxygen molecules in white blood cells, the lungs, and the stomach mucosa.[27] The antioxidant properties of vitamin C are also important for the functioning of other nutrients. Vitamin C donates an electron to regenerate the active antioxidant form of vitamin E and enhances iron absorption by keeping iron in its more readily absorbed reduced form (Fe^{2+}). When about 50 mg of vitamin C—the amount in a small glass of orange juice—is consumed in a meal containing iron, iron absorption is enhanced sixfold (see Chapter 12).

Vitamin C Deficiency

When vitamin C intake is below 10 mg/day, the symptoms of scurvy may appear. These symptoms reflect the role of vitamin C in the maintenance of collagen. Like all other body proteins, collagen is continuously being broken down and re-formed. Without vitamin C, the bonds holding adjacent collagen molecules together cannot be formed, so the collagen that is broken down is replaced with abnormal collagen. The inability to form healthy collagen prevents wounds from healing normally and causes bone and joint aches, bone fractures, and improperly formed and loose teeth. Connective tissue is also important for blood vessel integrity. A vitamin C deficiency therefore causes weakened blood vessels and ruptured capillaries. This leads to easy bruising, tiny bleeds under the skin around the hair follicles, bleeding gums, and bleeding into the joints that causes joint pain and weakness (**Figure 8.30**). Iron absorption is reduced when vitamin C is deficient. This reduced absorption, along with blood loss, contributes to anemia. The psychological manifestations of scurvy include depression and hysteria.

In the United States today, severe vitamin C deficiency leading to scurvy is rare, but marginal vitamin C deficiency is a concern for individuals who consume few fruits and vegetables. Scurvy has been reported in infants fed diets consisting exclusively of cow's milk, in alcoholics, and in elderly individuals consuming nutrient-poor diets.

Recommended Vitamin C Intake

Humans are one of only a few animal species that require vitamin C in the diet. Most animals can synthesize vitamin C in their bodies. For example, a pig makes 8 g of the vitamin each day.

Science Photo Library/Photo Researchers, Inc.

FIGURE 8.30
Symptoms of scurvy
When vitamin C is deficient, the symptoms of scurvy begin to appear. The gums become inflamed, swell, and bleed. The teeth become loose and eventually fall out.

The recommendations for vitamin C intake are based on the amount needed to maximize concentrations in neutrophils, a type of white blood cell, with minimal excretion of the vitamin in the urine. The RDA is 90 mg/day for men and 75 mg/day for women. This amount is easily obtained by drinking an 8-oz glass of orange juice.

LIFE CYCLE

The RDA for vitamin C is increased during pregnancy and lactation. The recommendation for infants is based on the vitamin C content of human milk (see inside cover). Cigarette smoking increases the requirement for vitamin C because vitamin C is used to break down compounds in cigarette smoke. It is recommended that cigarette smokers consume an extra 35 mg of vitamin C daily[27]—the amount in a half-cup of broccoli. Exercise and mental and emotional stress have not been found to affect the need for vitamin C.

Vitamin C Toxicity and Supplements

Vitamin C is generally considered nontoxic. Large increases in intake do not cause large increases in the amount of vitamin C in body fluids. This is because the percentage of the dose absorbed decreases as the size of the dose increases, and vitamin C absorbed in excess of need is excreted by the kidneys. The most common symptoms that occur with consumption of vitamin C doses of 3000 mg or more are diarrhea, nausea, and abdominal cramps.[27] These are caused when unabsorbed vitamin C draws water into the intestine. The UL for vitamin C is based on an amount that is unlikely to cause gastrointestinal symptoms in healthy individuals and has been set at 2000 mg/day from food and supplements.

Vitamin C supplements should be avoided by some individuals. In people prone to kidney stones, excess vitamin C can increase stone formation.[28] In individuals who are unable to regulate iron absorption, taking vitamin C supplements, which increase iron absorption, increases the risk that toxic amounts of iron will be stored. For those with sickle cell disease, excess vitamin C can worsen symptoms. In those taking medication to reduce blood clotting, taking more than 3000 mg/day of vitamin C can interfere with the effectiveness of the medication. Because the structure of vitamin C is similar to that of glucose, high doses can interfere with urine tests used to monitor glucose levels. A concern with high doses of chewable vitamin C supplements is that they can dissolve tooth enamel.

Do Vitamin C Supplements Cure the Common Cold? One-third of the population of the United States take supplements of vitamin C in hope of preventing or reducing symptoms of the common cold. Studies examining the relationship between vitamin C and the common cold date back to the 1930s. A review of placebo-controlled trials that supplemented diets with vitamin C failed to find that routine vitamin C supplementation reduced the incidence of colds in the healthy population, but regular supplementation with doses above 200 mg/day may slightly reduce the duration of cold symptoms (Figure 8.31).[29] The effect of vitamin C on cold symptoms may be due to its direct antiviral effect, its antioxidant effect, its role in stimulating various aspects of immune function, its ability to increase the breakdown of histamine (a molecule that causes inflammation), or a combination of these.

Can Vitamin C Supplements Protect against Cardiovascular Disease? Vitamin C supplements have been suggested to reduce the risk of cardiovascular disease by promoting the health and growth of the cells lining the blood vessels, preventing the oxidation of LDL cholesterol, and

© Will Selarep/iStockphoto

FIGURE 8.31 Vitamin C and the common cold Vitamin C supplements won't prevent you from catching a cold, but they may help you recover faster.

reducing blood cholesterol levels. Vitamin C is suggested to prevent LDL oxidation because of its antioxidant function. Vitamin C may reduce blood cholesterol because it is involved in the synthesis of bile acids from cholesterol in the liver. Adequate vitamin C allows cholesterol to be used for bile synthesis and therefore may reduce the amount of cholesterol in the blood. Although higher blood levels and dietary intakes of vitamin C are associated with a lower risk of cardiovascular disease, long-term controlled trials of vitamin C supplementation did not find supplements to affect the risk of cardiovascular disease.[30] Dietary patterns that are high in antioxidants, rather than supplements of individual nutrients, are more likely to protect against cardiovascular disease.

Do Vitamin C Supplements Protect against Cancer? It has been suggested that high doses of vitamin C both prevent and treat cancer. In terms of prevention, high intakes of vitamin C–rich foods (fruits and vegetables) have been linked to a lower incidence of a variety of different types of cancer, and plasma vitamin C concentrations are inversely associated with cancer risk. Despite the benefits of a dietary pattern high in vitamin C, supplements of vitamin C have not been shown to protect against cancer.[31,32]

Vitamin C has been studied extensively for its effectiveness in treating cancer. High doses of ascorbic acid are administered both orally and intravenously to patients with cancer in the hope that it will enhance the anticancer effects of chemotherapy and reduce its toxicity. There is currently no high-quality evidence that this treatment is beneficial.[33]

8.11 Choline and Other Vitamin-Like Compounds

LEARNING OBJECTIVES

- Explain why choline is considered an essential nutrient.
- Name two foods that are good sources of choline.

A number of substances perform vitamin-like functions in the body, but are not classified as vitamins because adequate amounts can be synthesized in the body so that they are not required in the diet. For example, carnitine is needed to transport fatty acids into the mitochondria where they are broken down to produce ATP. Lipoic acid functions as a coenzyme, and inositol is important for membrane function. Choline, although not currently classified as a vitamin, is recognized as an essential nutrient for which a dietary recommendation has been established.

Choline is a water-soluble substance that you may see included in supplements called *vitamin B complex*. It is needed for the synthesis of the neurotransmitter acetylcholine, the structure and function of cell membranes, lipid transport, and homocysteine metabolism. Because of these important roles, it is believed that deficiency could play a role in liver disease, atherosclerosis, and neurological disorders. Deficiency during pregnancy can interfere with brain development in the fetus, and deficiency in adults causes fatty liver and muscle damage.[34]

TABLE 8.4 A Summary of the Water-Soluble Vitamins and Choline (All Values Are RDAs Unless Otherwise Noted)

Vitamin	Sources	Recommended intake for adults	Major functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
Thiamin (vitamin B_1, thiamin mononitrate)	Pork, whole and enriched grains, seeds, nuts, legumes	1.1–1.2 mg/day	Coenzyme in glucose and energy metabolism; needed for neurotransmitter synthesis and normal nerve function	Beriberi: weakness, apathy, irritability, nerve tingling, poor coordination, paralysis, heart changes	Individuals with alcoholism, those living in poverty	None reported	ND
Riboflavin (vitamin B_2)	Dairy products, whole and enriched grains, dark green vegetables, meats	1.1–1.3 mg/day	Coenzyme in energy and lipid metabolism	Inflammation of the mouth and tongue, cracks at corners of the mouth	None	None reported	ND
Niacin (nicotinamide, nicotinic acid, vitamin B_3)	Beef, chicken, fish, peanuts, legumes, whole and enriched grains; can be made from tryptophan	14–16 mg NE/day	Coenzyme in energy metabolism and lipid synthesis and breakdown	Pellagra: diarrhea, dermatitis on areas exposed to sun, dementia	Those consuming a limited diet based on corn; individuals with alcoholism	Flushing, nausea, rash, tingling extremities	35 mg/day from fortified foods and supplements
Biotin	Liver, egg yolks; synthesized in the gut	30 μg/day[a]	Coenzyme in glucose synthesis and energy and fatty acid metabolism	Dermatitis, nausea, depression, hallucinations	Those consuming large amounts of raw egg whites; individuals with alcoholism	None reported	ND
Pantothenic acid (calcium pantothenate)	Meat, legumes, whole grains; widespread in foods	5 mg/day[a]	Coenzyme in energy metabolism and lipid synthesis and breakdown	Fatigue, rash	Individuals with alcoholism	None reported	ND
Vitamin B_6 (pyridoxine, pyridoxal phosphate, pyridoxamine)	Meat, fish, poultry, legumes, whole grains, nuts and seeds	1.3–1.7 mg/day	Coenzyme in protein and amino acid metabolism, neurotransmitter and hemoglobin synthesis, many other reactions	Headache, convulsions, other neurological symptoms, nausea, poor growth, anemia	Individuals with alcoholism	Numbness, nerve damage	100 mg/day
Folate (folic acid, folacin, pteroylglutamic acid)	Leafy green vegetables, legumes, seeds, enriched grains, orange juice	400 μg DFE/day	Coenzyme in DNA synthesis and amino acid metabolism	Macrocytic anemia, inflammation of tongue, diarrhea, poor growth, neural tube defects	Pregnant women, individuals with alcoholism	Masks B_{12} deficiency	1000 μg/day from fortified food and supplements
Vitamin B_{12} (cobalamin, cyanocobalamin)	Animal products	2.4 μg/day	Coenzyme in folate and homocysteine metabolism; nerve function	Pernicious anemia, macrocytic anemia, nerve damage	Vegans, older adults, people with stomach or intestinal disease	None reported	ND
Vitamin C (ascorbic acid, ascorbate)	Citrus fruit, broccoli, strawberries, leafy green vegetables, peppers	75–90 mg/day	Coenzyme in collagen (connective tissue) synthesis; hormone and neurotransmitter synthesis; antioxidant	Scurvy: poor wound healing, bleeding gums, loose teeth, bone fragility, joint pain, pinpoint hemorrhages	Individuals with alcoholism, older adults	GI distress, diarrhea	2000 mg/day
Choline[b]	Egg yolks, organ meats, wheat germ, meat, fish, nuts; synthesis in the body	425–550 mg/day[a]	Synthesis of cell membranes and neurotransmitters	Fatty liver, muscle damage, abnormal prenatal development	None	Sweating, low blood pressure, liver damage	3500 mg/day

[a]Adequate Intake (AI).

[b]Choline is technically not a vitamin, but recommendations have been made for its intake.

Note: UL, Tolerable Upper Intake Level; NE, niacin equivalent; DFE, dietary folate equivalent; ND, not determined due to insufficient data.

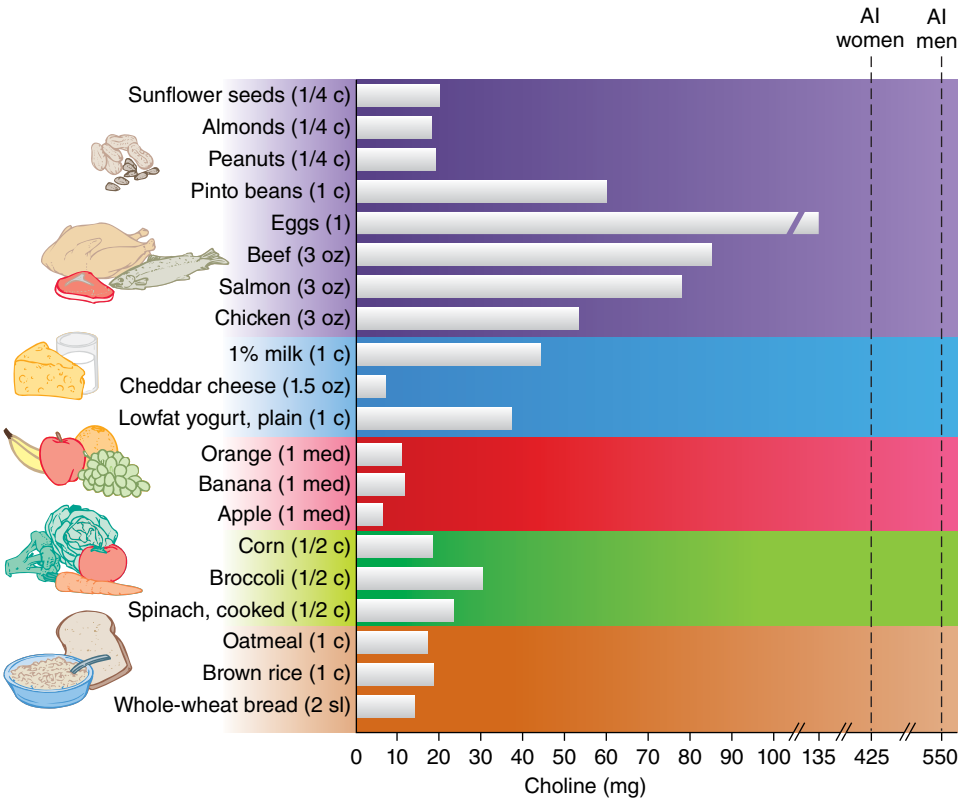


FIGURE 8.32 Choline content of MyPlate food groups[35]
Most foods provide some choline, but eggs and meats are the best sources. The dashed lines represent the AIs for women and men.

Choline can be synthesized in the human body, but the amounts are generally not high enough to meet needs. Choline is found in many foods. The best dietary sources of choline are egg yolks, liver, meat and fish, whole grains, and nuts (Figure 8.32).[35] The DRIs have set AIs for this compound: 550 mg/day for men and 425 mg/day for women.[5] There is concern that current choline intakes are below recommendations for certain segments of the population, but it is not clear how this is affecting public health.

Excess choline intake can cause a fishy body odor, sweating, reduced growth rate, low blood pressure, and liver damage. The amounts needed to cause these symptoms are much higher than can be obtained from foods. The UL for choline for adults is 3.5 g/day.

A summary of the sources, recommended intakes, functions, deficiencies, and toxicities of the water-soluble vitamins and choline is provided in Table 8.4.

OUTCOME

When Gary's anemia and vitamin C deficiency were treated with a multivitamin and an iron supplement, he started feeling better almost immediately. He worked with the dietitian to plan a diet that fit his budget and met his need for iron and vitamin C as well as other essential nutrients. She taught him that red meat and fortified cereals are good sources of iron and explained that without fruits and vegetables, his diet provided very little vitamin C. Without vitamin C, he was not efficiently absorbing the iron in the fortified grain products he did consume and his iron losses were increased. To address his fruit and vegetable intake, she suggested that he add frozen vegetables to his noodles, watch for seasonal produce on sale, and buy canned fruits and vegetables, which are generally inexpensive. She also suggested baked potatoes topped with salsa and cheese, and pasta with ground beef and tomato sauce as low-cost meals that provide both iron and vitamin C. By following her suggestions he was able to eat a few servings of fruits and vegetables every day and still keep to a budget. Gary's diet still doesn't meet recommendations for fruits and vegetables, but he is getting plenty of iron and vitamin C. **He expects to complete his degree in the spring and he's lucky enough to have a job lined up and plans to use some of his paycheck to further improve his diet.**

SUMMARY

8.1 What Are Vitamins?

- Vitamins are essential organic nutrients that do not provide energy and are required in small quantities in the diet. Americans consume vitamins that are naturally present in foods, added to foods by fortification, and supplied by supplements. Some foods are fortified with nutrients according to government guidelines to promote public health. Others are fortified according to the manufacturer's perceptions of what will sell in the marketplace.
- The bioavailability of a vitamin depends on how much can be absorbed and used by the body. The ability to store and excrete vitamins helps to regulate the amount present in the body. Water-soluble vitamins are generally excreted more easily than and not stored as well as fat-soluble vitamins.
- Vitamins are needed to promote and regulate body processes that are essential for growth, reproduction, and tissue maintenance. Each vitamin has one or more functions: Many are coenzymes, some are antioxidants. More than one vitamin is typically needed to ensure the health of a particular organ or system.
- Vitamin deficiencies remain a major health problem worldwide, but severe deficiencies are rare in developed countries. Recommended intakes for vitamins are expressed as RDAs or AIs. UL values estimate the highest dose that is unlikely to cause toxicity. Food labels can help identify packaged foods that are good sources of vitamins.

Go to WileyPLUS to view a video clip on vitamin supplements.

8.2 Thiamin

- The best food sources of thiamin are lean pork, legumes, and whole or enriched grains.
- Thiamin is required for the formation of acetyl-CoA from pyruvate and for a reaction in the citric acid cycle and is therefore particularly important for the production of ATP from glucose. It is also needed for the synthesis of the neurotransmitter acetylcholine.
- Thiamin deficiency causes nervous system abnormalities (dry beriberi) or cardiovascular problems (wet beriberi). Deficiencies are common in people with alcoholism. No toxicity has been identified.

8.3 Riboflavin

- Milk, meat, and whole and enriched grains are the best food sources of riboflavin.
- Riboflavin coenzymes are needed for the generation of ATP from carbohydrate, fat, and protein.
- Riboflavin deficiency is rarely seen alone because food sources of riboflavin are also sources of other B vitamins and because riboflavin is needed for the utilization of several other vitamins. No toxicity has been identified.

8.4 Niacin

- Beef, chicken, turkey, fish, and whole and enriched grains are the best food sources of niacin. The amino acid tryptophan can be converted into niacin, so tryptophan from dietary protein can meet some of the niacin requirement.
- Niacin coenzymes are important in the breakdown of carbohydrate, fat, and protein to provide energy and in the synthesis of fatty acids and sterols.
- Niacin deficiency results in pellagra, which is characterized by dermatitis, diarrhea, dementia, and finally, if untreated, death.
- Supplements of the nicotinic acid form of niacin can lower elevated blood cholesterol but frequently cause toxicity symptoms such as flushing, tingling sensations, nausea, and a red skin rash.

8.5 Biotin

- Liver and egg yolks are good sources of biotin.
- Biotin is needed for the synthesis of glucose and fatty acids and for the metabolism of certain amino acids.
- An RDA has not been established for biotin because some of our requirement for this vitamin is met by bacterial synthesis in the GI tract. However, an AI has been set. Toxicity has not been reported.

8.6 Pantothenic Acid

- Pantothenic acid is abundant in the food supply and deficiency is rare.
- Pantothenic acid is part of CoA, which is required for the production of ATP from carbohydrate, fat, and protein and the synthesis of cholesterol and fatty acids. There is no RDA, but an AI has been established.

8.7 Vitamin B_6

- Food sources of vitamin B_6 include chicken, fish, liver, and whole grains.
- Pyridoxal phosphate, the coenzyme form of vitamin B_6, is needed for the activity of more than 100 enzymes involved in the metabolism of carbohydrate, fat, and protein. Vitamin B_6 is a coenzyme for transamination, deamination, and decarboxylation reactions and is therefore particularly important for amino acid metabolism.
- Vitamin B_6 deficiency causes neurological symptoms, anemia due to impaired hemoglobin synthesis, poor immune function, and elevated levels of homocysteine, which can increase the risk of cardiovascular disease. High intakes from supplements can cause nervous system abnormalities.

8.8 Folate (Folic Acid)

- Food sources of folate include liver, legumes, oranges, leafy green vegetables, and fortified grains.
- Folate is necessary for the synthesis of DNA, so it is especially important for rapidly dividing cells.
- Folate deficiency results in macrocytic anemia and can cause an increase in homocysteine levels. Low levels of folate before and during early pregnancy are associated with an increased incidence of neural tube defects in the offspring. A high intake of folate can mask the anemia caused by vitamin B_{12} deficiency. Low intakes of folate have been associated with an increased risk of cardiovascular disease and certain types of cancer.
- It is recommended that women of childbearing age consume 400 μg of folic acid from fortified foods and supplements in addition to the folate found in a varied diet.

8.9 Vitamin B_{12}

- Vitamin B_{12} is found almost exclusively in animal products.
- The absorption of vitamin B_{12} from food requires adequate levels of stomach acid, intrinsic factor, and pancreatic secretions.

- Vitamin B_{12} is needed for the metabolism of folate and fatty acids and to maintain the insulating layer of myelin surrounding nerves.
- Vitamin B_{12} deficiency increases homocysteine levels and can result in anemia and permanent nerve damage. Pernicious anemia is an autoimmune disease that results in severe vitamin B_{12} deficiency due to an absence of intrinsic factor. Vitamin B_{12} deficiency may also occur in vegans, who consume no animal products, and in older individuals with low stomach acid due to atrophic gastritis.

8.10 Vitamin C

- The best food sources of vitamin C are citrus fruits.
- Vitamin C is necessary for the synthesis and maintenance of collagen and for the synthesis of hormones and neurotransmitters. Vitamin C is also a water-soluble antioxidant. Antioxidants protect the body from reactive oxygen molecules such as free radicals. These molecules are generated from normal body reactions and come from the environment. They cause damage by stealing electrons from DNA, proteins, carbohydrates, and unsaturated fatty acids.
- Vitamin C deficiency, called scurvy, is characterized by poor wound healing, bleeding, and other symptoms related to the improper formation and maintenance of collagen.
- Vitamin C supplements are the most commonly taken vitamin supplements and are usually used to reduce the symptoms of the common cold.

8.11 Choline and Other Vitamin-Like Compounds

- There are a number of substances, such as carnitine, lipoic acid, and inositol, that perform vitamin-like functions in the body, but are not classified as vitamins because adequate amounts can be synthesized.
- Choline is considered an essential nutrient but is not currently classified as a vitamin. Choline can be synthesized in the human body, but the amounts are generally not enough to meet needs. The best dietary sources of choline are egg yolks and meats.

CHAPTER OUTLINE

9.1 Fat-Soluble Vitamins in Our Diet

9.2 Vitamin A Sources and Functions
Vitamin A in the Diet
Vitamin A in the Digestive Tract
How Vitamin A Functions in the Body

9.3 Meeting Vitamin A Needs
Vitamin A Deficiency
Recommended Vitamin A Intake
Vitamin A Toxicity and Supplements

9.4 Vitamin D
Vitamin D in the Diet
How Vitamin D Functions in the Body
Vitamin D Deficiency
Recommended Vitamin D Intake
Meeting Vitamin D Needs
Vitamin D Toxicity

9.5 Vitamin E
Vitamin E in the Diet
How Vitamin E Functions in the Body
Vitamin E Deficiency
Recommended Vitamin E Intake
Vitamin E Toxicity and Supplements

9.6 Vitamin K
Vitamin K in the Diet
How Vitamin K Functions in the Body
Vitamin K Deficiency
Recommended Vitamin K Intake
Vitamin K Toxicity and Supplements

9.7 Vitamin/Mineral Supplements
Who Needs Vitamin/Mineral Supplements?
Choose Supplements with Care

(©iStockphoto)

DNY59/iStockphoto

The Fat-Soluble Vitamins

9

CASE STUDY

Ayana's pediatrician is concerned because at age 1 she has just one tooth. Her mother breast-fed her from birth, and she has been eating some solid foods since she was about 6 months old. After noticing that she has only one tooth and examining her ribs and legs, the doctor tells Ayana's parents that she wants to draw a blood sample to help confirm her suspicion that Ayana has a vitamin D deficiency disease called *rickets*. The pediatrician explains that this deficiency is relatively rare in the United States, but risks are higher in children who are dark skinned, live in cold climates, and/or are breast-fed without vitamin D supplementation. Ayana's family lives in Idaho where the winters are long and the skies cloudy, reducing potential time spent outdoors in the sun. Although breast milk is best for babies, it is low in vitamin D. Vitamin D can be synthesized in the skin, but because Ayana has dark skin pigmentation, she requires greater sun exposure than lighter-skinned babies to synthesize adequate amounts.

Vitamin D is needed for proper formation and maintenance of bones and teeth. Without sufficient vitamin D, a child's legs bow under the weight of standing and bony bumps appear on each of the ribs. The poorly formed bones can easily break. The teeth erupt late and are very prone to decay. Ayana is beginning to show these symptoms. Rickets is diagnosed with bone X-rays and blood tests that measure levels of calcium and phosphorus, as well as levels of an enzyme produced by cells that break down bone.

Like Ayana's parents, most people in the United States are not familiar with rickets. **Recent evidence, however, suggests that rickets due to vitamin D deficiency may be reemerging as a problem in the U.S. population.**[1,2]

Digital Vision/Getty Images, Inc.

9.1 Fat-Soluble Vitamins in Our Diet

LEARNING OBJECTIVES

- Name the fat-soluble vitamins.
- Discuss factors that impact fat-soluble vitamin status in the United States.

The fat-soluble vitamins—A, D, E, and K—are found along with fats in foods. Because they are fat soluble, they require special handling for absorption into and transport throughout the body. They require bile and dietary fat for absorption. Once absorbed, they are transported with lipids through the lymphatic system in chylomicrons before entering the blood (see Chapter 5). Because excesses of these vitamins can be stored in the liver and fatty tissues, intakes can vary without a risk of deficiency as long as average intake over a period of weeks or months meets needs. Solubility in fat, however, limits their routes of excretion and therefore increases the risk of toxicity.

Tatiana Emshanova/iStockphoto

FIGURE 9.1 Leafy greens are a source of fat-soluble vitamins
Dark green leafy vegetables such as this Swiss chard are good low-calorie sources of vitamin A precursors, as well as vitamin E and vitamin K.

Despite the body's ability to store the fat-soluble vitamins, deficiencies of vitamin A and D are common in the developing world. Elimination of these deficiencies through supplementation and fortification is a focus of public health programs. In the United States and other developed countries, severe deficiencies of these nutrients are rare, but trends in the modern diet have affected the amounts of fat-soluble vitamins people consume. Our rising reliance on processed, packaged, and fast food has reduced our intake of fruits and vegetables, particularly leafy greens, reducing our intake of vitamins A, E, and K (Figure 9.1). We work at indoor jobs, exercise at indoor gyms, and protect ourselves from the sun by using sunscreens when we go out, all of which limit our ability to get adequate vitamin D from sunshine. We drink soda instead of milk, which decreases our intake of vitamins A and D. We cut fat to reduce calories, but vegetable oils provide much of our vitamin E as well as fat-soluble phytochemicals, some of which serve as precursors to vitamin A. Medications that limit fat absorption also limit fat-soluble vitamin absorption. To avoid the risks of limited intakes, we take supplements of these vitamins and fortify our food with them. This then increases the risks of consuming toxic amounts. It is unclear whether these new dietary patterns will have a long-term impact on our fat-soluble vitamin status.

9.2 Vitamin A Sources and Functions

LEARNING OBJECTIVES

- Compare the sources, functions, and potential toxicity of preformed vitamin A and provitamin A.
- Describe the role of vitamin A in night vision.
- Discuss how vitamin A affects gene expression.

Did you ever hear that eating carrots would help you see in the dark? It turns out to be true. Carrots are high in provitamin A, and vitamin A is important for vision and healthy eyes. This connection between vision and foods that we now know are high in vitamin A has been recognized for centuries. In ancient times, the Egyptians knew that eating liver could improve night vision in those who had difficulty adjusting from bright light to dim light. In 1968, George Wald earned the Nobel Prize in medicine for identifying the mechanism by which vitamin A is involved in vision. Although this is a key function of vitamin A, attention today is focused more on how

vitamin A interacts with genes to regulate growth and **cell differentiation**. Despite our expanding understanding of the functions of vitamin A, deficiency remains a world health problem.

cell differentiation Structural and functional changes that cause cells to mature into specialized cells.

Vitamin A in the Diet

Vitamin A is found preformed and in precursor or provitamin forms in our diet. Preformed vitamin A is found in animal foods, and the provitamin A forms are found in plants (Figure 9.2). Both sources can be used to meet vitamin A needs in the body.

Preformed vitamin A compounds are known as **retinoids**. Three retinoids are active in the body: retinol, retinal, and retinoic acid. Animal foods such as liver, fish, egg yolks, and dairy products provide preformed vitamin A, primarily as retinol attached to a fatty acid (retinyl ester). Margarine and nonfat and reduced-fat milk are fortified with retinol because they are often consumed in place of butter and whole milk, which are good natural sources of this vitamin. Retinal and retinoic acid can be formed in the body from retinol (Figure 9.3).

retinoids The chemical forms of preformed vitamin A: retinol, retinal, and retinoic acid.

Plants contain provitamin A compounds called **carotenoids**. Carotenoids are yellow, orange, and red pigments that give these colors to fruits and vegetables. About 50 of the 600 carotenoids that have been isolated provide vitamin A activity. **Beta-carotene (β-carotene)**, the most potent precursor (see Figure 9.3), is plentiful in dark orange fruits and vegetables such as mangos, apricots, cantaloupe, carrots, pumpkins, and sweet potatoes as well as in leafy greens where the orange color is masked by the green of chlorophyll. Other carotenoids that provide some provitamin A activity include alpha-carotene (α-carotene), found in carrots, dark green vegetables, and winter squash, and beta-cryptoxanthin (β-cryptoxanthin), found in mangos, papayas, winter squash, and sweet red peppers.[3] Lutein, lycopene, and zeaxanthin are carotenoids with no vitamin A activity (see Focus on Phytochemicals).

carotenoids Natural pigments synthesized by plants and many microorganisms. They give yellow, orange, and red fruits and vegetables their color.

beta-carotene (β-carotene) A carotenoid that has more provitamin A activity than other carotenoids. It also acts as an antioxidant.

To help consumers identify food sources of vitamin A, labels on packaged foods currently must list the vitamin A content as a percentage of the Daily Value. All forms of vitamin A in the diet are fairly stable when heated but may be destroyed by exposure to light and oxygen.

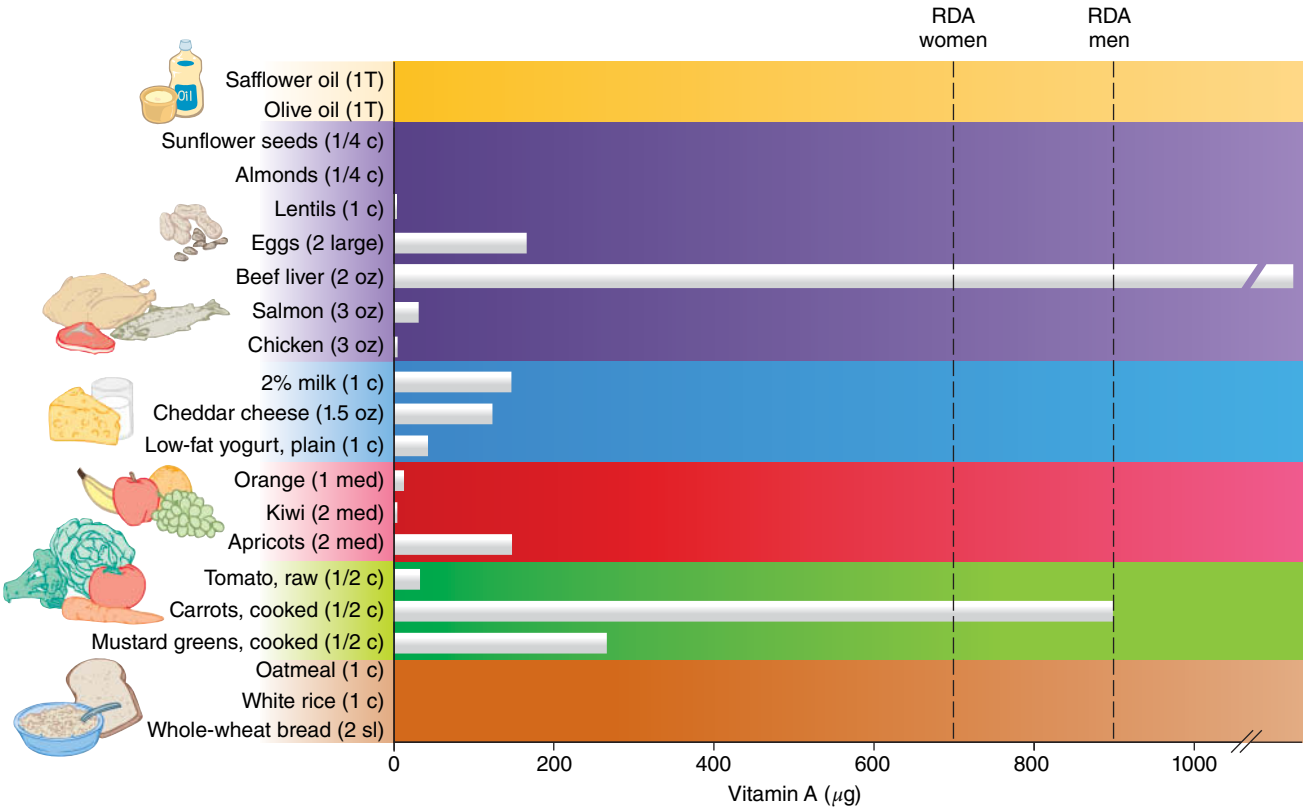


FIGURE 9.2 Vitamin A content of MyPlate food groups
Eggs, liver, and dairy products are good sources of preformed vitamin A, and most yellow-orange and leafy green fruits and vegetables are good sources of provitamin A carotenoids; grains are generally poor sources of vitamin A. The dashed lines show the RDAs for women and men.

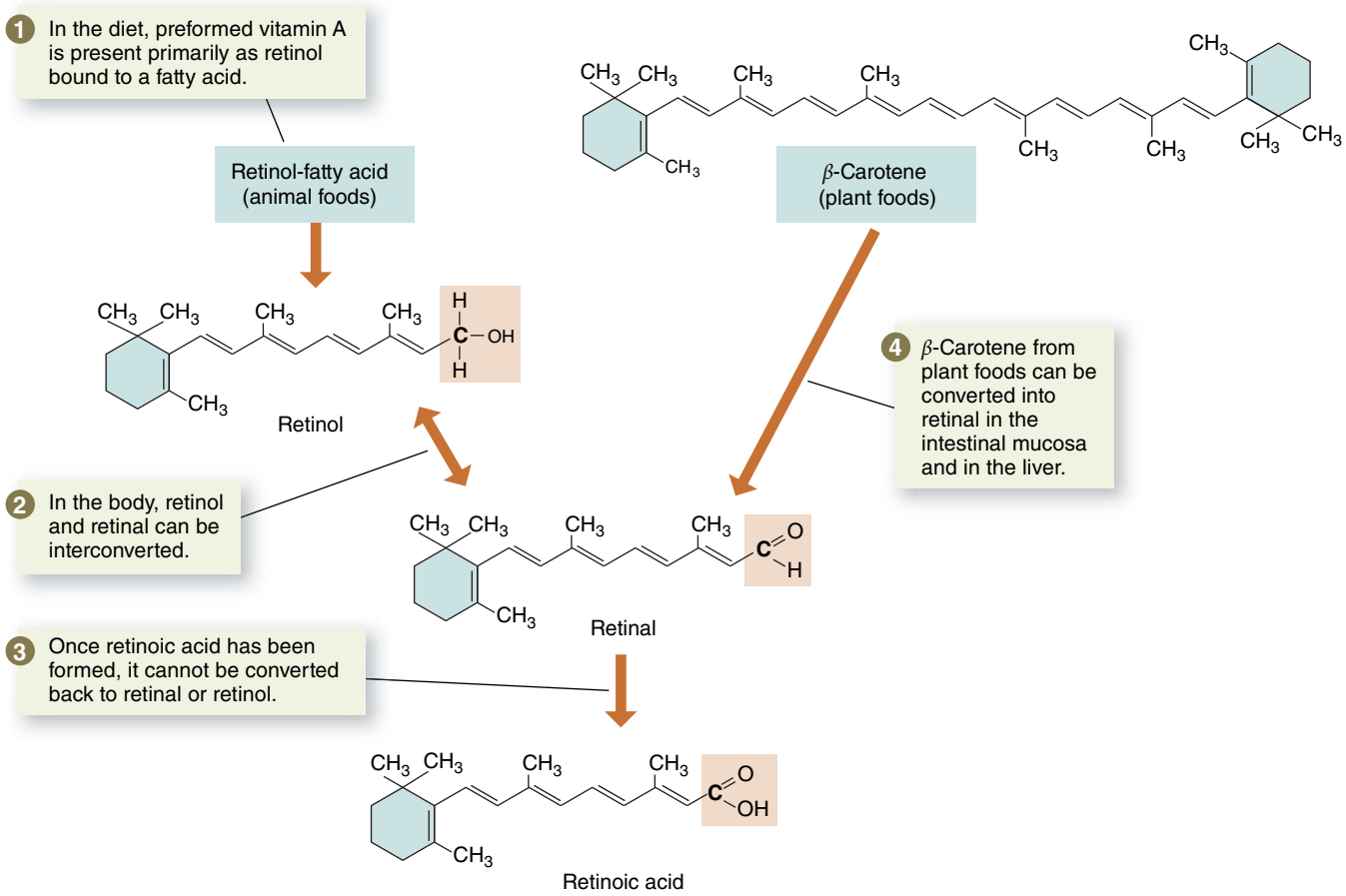


FIGURE 9.3 Forms of vitamin A
Both preformed vitamin A and provitamin A carotenoids from the diet can supply the retinol, retinal, and retinoic acid forms of vitamin A. Retinol and retinal can be interconverted from one to the other but the reaction that forms retinoic acid is not reversible.

Vitamin A in the Digestive Tract

Both preformed vitamin A and carotenoids are bound to proteins in foods. To be absorbed, they must be released from the protein by pepsin and other protein-digesting enzymes. In the small intestine, the released retinol and carotenoids combine with bile acids and other fat-soluble food components to form micelles, which facilitate their diffusion into mucosal cells (see Chapter 5). Absorption of preformed vitamin A is efficient—70 to 90% of what is consumed. The provitamin carotenoids are less well absorbed, and absorption decreases as intake increases, so large amounts are not well absorbed.[4] Once inside the mucosal cells, much of the β-carotene is converted to retinal. Cleaving a molecule of β-carotene in half theoretically yields two molecules of retinal; however, because β-carotene is not as well absorbed as preformed vitamin A and may not be efficiently converted to retinal, it takes about 12 μg of dietary β-carotene to yield 1 μg of retinol (see Figure 9.3).

The fat content of the diet and the ability to absorb fat can affect the amount of vitamin A that is absorbed. A diet that is very low in fat (less than 10 g/day) can reduce vitamin A absorption. This is rarely a problem in industrialized countries, where typical fat intake ranges from 50 to 100 g/day. However, in populations with low dietary fat intakes, vitamin A deficiency may occur due to poor absorption. Diseases that cause fat malabsorption, as well as some medications, can also interfere with vitamin A absorption and cause a deficiency.

How Vitamin A Functions in the Body

Preformed vitamin A and carotenoids absorbed from the diet are transported from the small intestine in chylomicrons. These lipoproteins deliver the preformed vitamin A and carotenoids

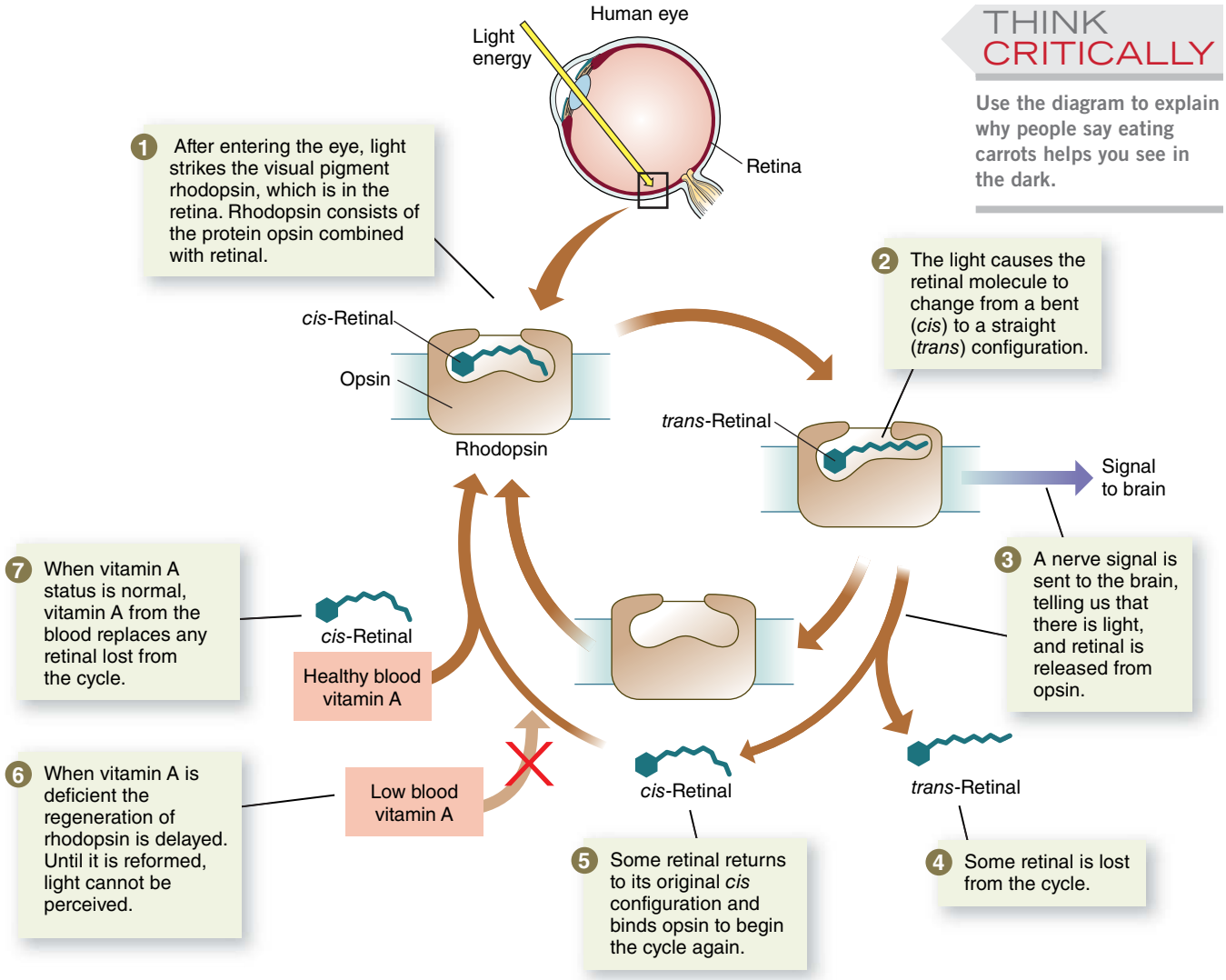
to body tissues such as muscle, kidney, and liver. Although most of the conversion of carotenoids to retinoids occurs in the small intestine, some can also occur in the liver. Both preformed vitamin A and carotenoids are stored in the liver; carotenoids are also stored in fatty tissues throughout the body. To move from liver stores to the tissues, retinol must be bound to **retinol-binding protein**. There is no specific blood transport protein for carotenoids, but since they are fat soluble, they are incorporated into lipoproteins to travel in the bloodstream.

retinol-binding protein A protein that is necessary to transport vitamin A from the liver to other tissues.

The different forms of vitamin A have different functions. The body can make the retinal and retinoic acid forms from the retinol and carotenoids in the diet (see Figure 9.3). Retinol is the form that circulates in the blood. Retinal is the form that is important for vision. Retinoic acid, which is made from retinal, cannot be used in the visual cycle (see the next section) but is the form that affects gene expression and is responsible for vitamin A's role in cell differentiation, growth, and reproduction.[5] Carotenoids that are not converted to retinoids may act as antioxidants or provide other biological functions.

rhodopsin A light-absorbing compound found in the retina of the eye that is composed of the protein opsin loosely bound to retinal.

How Vitamin A Helps Us to See Light Vitamin A is involved in the perception of light. In the eye, the retinal form of the vitamin combines with the protein opsin to form the visual pigment **rhodopsin** (Figure 9.4). Rhodopsin helps transform the energy from light into a nerve impulse that is sent to the brain. This nerve impulse allows us to see.



THINK CRITICALLY

Use the diagram to explain why people say eating carrots helps you see in the dark.

FIGURE 9.4 The visual cycle
Looking into the bright headlights of an approaching car at night is temporarily blinding for all of us, but for someone with vitamin A deficiency the blindness lasts much longer. This occurs because of the role of vitamin A in the visual cycle.

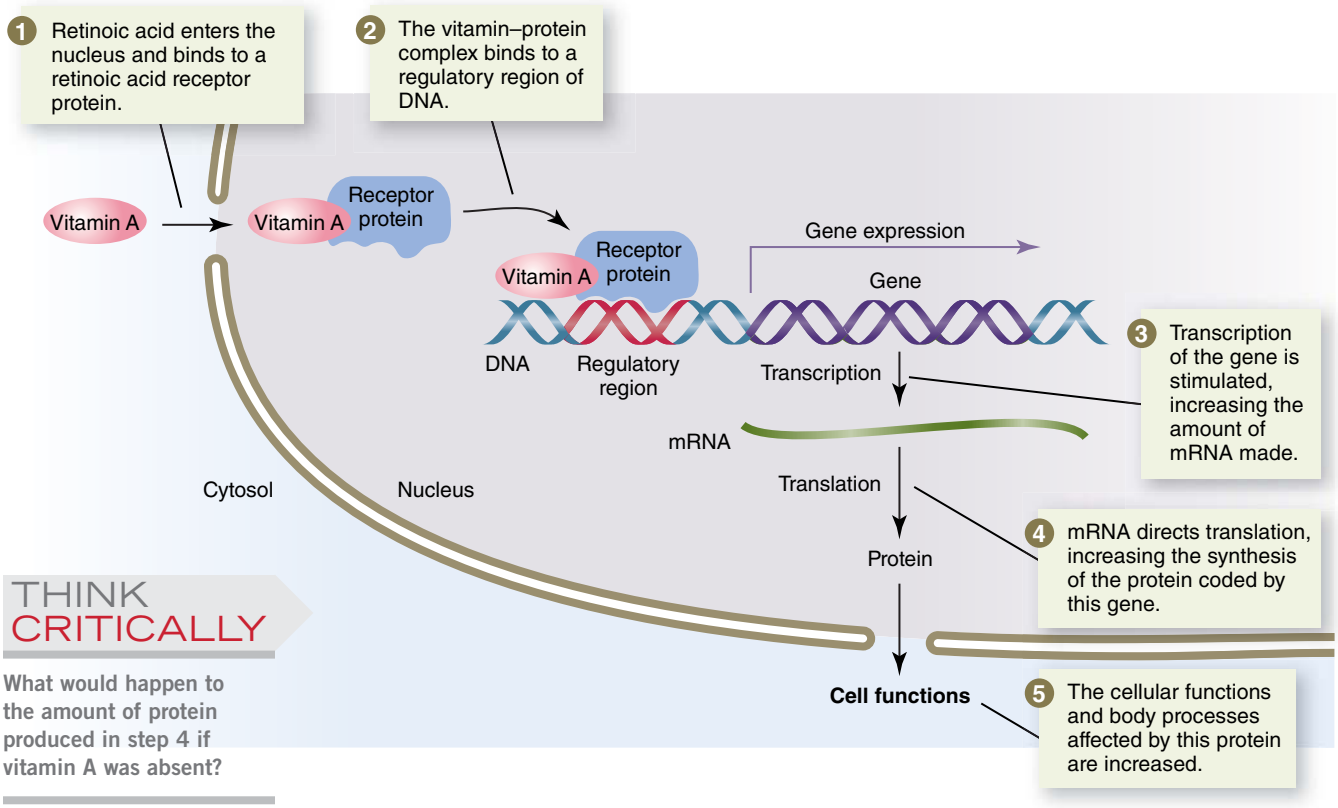
The visual cycle begins when light passes into the eye and strikes rhodopsin. The light changes the retinal in rhodopsin from a curved molecule to a straight one by converting a *cis* double bond in retinal to a *trans* double bond. This change in shape initiates a series of events that cause a nerve signal to be sent to the brain and retinal to be released from opsin. After the light stimulus has passed, the *trans* retinal is converted back to its original *cis* form and recombined with opsin to regenerate rhodopsin. Each time this cycle occurs, some retinal is lost and must be replaced by retinol from the blood. The retinol is converted into retinal in the eye. When vitamin A is deficient, the regeneration of rhodopsin is delayed, which causes difficulty seeing in dim light, particularly after exposure to a bright light—a condition called **night blindness** (see Figure 9.4). Night blindness is one of the first and more easily reversible symptoms of vitamin A deficiency.

night blindness The inability of the eye to adapt to reduced light, causing poor vision in dim light.

How Vitamin A Regulates Gene Expression The retinoic acid form of vitamin A is needed for normal gene expression. When a specific gene is expressed, it instructs the cell to make a particular protein. Proteins have structural and regulatory functions within cells and throughout the body. Altering the expression of specific genes increases (or decreases) the production of certain proteins and thereby affects various cellular and body functions. When the retinoic acid form of vitamin A enters the nucleus of specific target cells, it binds to retinoic acid receptor proteins. The retinoic acid–protein complex then binds to a regulatory region of DNA, causing a change in the amount of messenger RNA (mRNA) that is made by the gene (Figure 9.5). The change in mRNA changes the amount of the protein that is produced. For example, vitamin A increases the expression of a gene that makes an enzyme in liver cells. This enzyme enables the liver to make glucose through the process of gluconeogenesis.

By affecting gene expression, vitamin A can determine what proteins a cell produces and what type of cell a cell will become as it differentiates. The role of vitamin A in cell

FIGURE 9.5 Vitamin A and gene expression
The retinoic acid form of vitamin A affects cell function by changing gene expression. The steps illustrate what happens when vitamin A turns on gene expression.



THINK CRITICALLY

What would happen to the amount of protein produced in step 4 if vitamin A was absent?

differentiation is particularly important for the maintenance of epithelial tissue. Epithelial tissue is the type of tissue that covers external body surfaces and lines internal cavities and tubes. It includes the skin and the linings of the eyes, intestines, lungs, vagina, and bladder. These cells have a short life span and need to be replaced often. Adequate vitamin A ensures that the old cells are replaced with normal healthy new ones. Vitamin A is also important for healthy immune function because it is needed for cells in the bone marrow to differentiate into the various types of white blood cells. The ability of vitamin A to regulate the growth and differentiation of cells also makes it essential throughout life for normal reproduction and growth.

β-Carotene Functions as a Vitamin A Precursor and an Antioxidant Some carotenoids, particularly β-carotene, can be converted to vitamin A in the intestinal mucosa and liver. Unconverted carotenoids also circulate in the blood and reach tissues where they may function as antioxidants, a role independent of any conversion to vitamin A. β-Carotene and other carotenoids are fat-soluble antioxidants that may play a role in protecting cell membranes from damage by free radicals. The antioxidant properties of carotenoids have stimulated interest in their ability to protect against diseases in which oxidative processes play a role, such as cancer, heart disease, and impaired vision due to macular degeneration or cataracts.

9.3 Meeting Vitamin A Needs

LEARNING OBJECTIVES

- Describe how low intakes of fat, protein, and zinc as well as vitamin A might contribute to vitamin A deficiency.
- Explain why a vitamin A deficiency can cause eye infections and blindness.
- Discuss the risks of excess vitamin A and excess β-carotene.

Vitamin A deficiency is uncommon in developed countries but it is a threat to the health, sight, and lives of millions of children in the developing world. It is estimated that more than 250 million preschool children worldwide are vitamin A deficient and that 250,000 to 500,000 children go blind annually due to vitamin A deficiency.[6] It is most common in India, Africa, Southeast Asia, and the Caribbean. Combating this deficiency has led to innovative ways of meeting needs with diet, supplements, fortification, and genetically modified crops (see **Debate: Combating Vitamin A Deficiency with Golden Rice**). Too much of this vitamin can also be toxic.

Vitamin A Deficiency

Clinical vitamin A deficiency is rare in the United States, but dietary intake surveys indicate that many Americans do not meet the recommendations for this vitamin.[17] Intakes below the RDA can be caused by poor food choices even when the food supply is plentiful. In the United States the intake of fruits and vegetables, many of which are excellent sources of provitamin A, does not meet recommendations (see **Critical Thinking: How Much Vitamin A Is in Your Fast-Food Meal?**).

In developing countries vitamin A deficiency can be caused by insufficient intakes of vitamin A, but also by low intakes of fat, protein, or the mineral zinc. As discussed, without fat, vitamin A cannot be absorbed, so a diet very low in fat can cause a deficiency by reducing vitamin A absorption. Protein deficiency can cause vitamin A deficiency because the retinol-binding protein needed to transport vitamin A from the liver cannot be made in sufficient quantities. The importance of zinc for vitamin A utilization is believed to be due to its role in protein synthesis. When zinc is deficient, the proteins needed for vitamin A transport and metabolism are lacking.

DEBATE

Combating Vitamin A Deficiency with Golden Rice

Each year, vitamin A deficiency takes the sight and lives of hundreds of thousands of children worldwide. The deficiency is most common in impoverished populations where the dietary staple is deficient in vitamin A. Currently, this deficiency is addressed using vitamin A supplementation, fortification of the food supply, and interventions that increase the variety of the diet to include foods that are rich in vitamin A. A more controversial solution is Golden Rice. This is rice that has been genetically modified (GM) to synthesize β-carotene, a precursor to vitamin A (see photo). Many believe that, if it replaced white rice as a staple, Golden Rice could alleviate vitamin A deficiency. However, the controversy that ensued after it was developed has kept the preventive potential of Golden Rice from being fully assessed.

Erik De Castro/Reuters/Newscom

The white rice shown on the left provides no vitamin A. The Golden Rice shown on the right gets its yellow, or golden, color from the vitamin A precursor β-carotene.

Initial concerns about Golden Rice focused on whether it would provide enough vitamin A to alleviate deficiency. The original variety provided so little β-carotene that a 2-year-old child would need to eat 3 kg of it each day to get enough vitamin A.[7] However, a newer variety contains enough β-carotene in ½ cup of dry rice (about 1 cup cooked) to provide about 430 μg of retinol, more than enough to meet the RDA for an 8-year-old child.[8] Critics of Golden Rice have expressed concern that the β-carotene in the rice might not provide usable vitamin A to the body. However, a recent study that compared the vitamin A value of the β-carotene in Golden Rice to that of a β-carotene supplement found that both resulted in similar blood levels of retinol.[8] Even though Golden Rice can provide enough vitamin A, many still argue that it may not necessarily be a solution to vitamin A malnutrition. Deficient populations typically suffer from other nutrient deficiencies in addition to vitamin A and when protein, fat, or zinc is deficient, the body can't efficiently use vitamin A.[9,10]

There is also concern that introducing Golden Rice, which is a GM organism, into the environment will cause harm. The worry is that its use will decrease the diversity of rice varieties grown. Reducing diversity increases the risk of crop destruction due to insects and disease.[9] Proponents of GM crops argue that this concern occurs whenever a new crop that is preferred by farmers is introduced and that the potential health benefits outweigh the environmental concerns (see Focus on Biotechnology). Opponents of Golden Rice also argue that it could exacerbate malnutrition by encouraging a diet based solely on rice.[11] Although the use of Golden Rice rather than white rice is unlikely to affect dietary diversity, switching to Golden Rice does little to address the underlying causes of malnutrition, which are poverty and lack of access to a varied diet.

While debate over the usefulness of Golden Rice continues, vitamin A deficiency remains a major public health issue. Opponents to this approach argue that work on Golden Rice has diverted resources from proven programs that address multiple nutrient deficiencies. Proponents contend that the problem is not the rice but rather the regulatory climate that has prevented it from being introduced.[12] Golden Rice has been ready for farmers since the beginning of the 21st century but it is still being tested, so is not available for widespread use.[13] In efforts to move production forward, former Greenpeace leaders have now endorsed the Allow Golden Rice Now! campaign in Europe to promote its use.[14,15] Even the Pope has gotten involved, and although the Vatican has not endorsed the use of Golden Rice, the Pope has given it his personal blessing.[16]

Science, politics, and now even religion are weighing in on Golden Rice. Everyone would likely agree that the goal is to prevent malnutrition and in the long term eliminate poverty, which reduces access to a healthy diet. GM crops such as Golden Rice alone may not be the solution to malnutrition. Supplementation may be necessary for those in immediate need, and fortification and supplementation may work better in urban settings. However, the question remains, should Golden Rice be part of the arsenal available to eliminate vitamin A deficiency?

THINK CRITICALLY: Why is it important to preserve all the varieties of rice that currently exist, even if we do not rely on them as dietary staples?

CRITICAL THINKING

How Much Vitamin A Is in Your Fast-Food Meal?

TNT Magazine/Alamy

John has been living in an apartment all junior year, eating a lot of fast food. He has heard that it is "bad for you" because it is too high in calories and too low in essential nutrients, particularly vitamin A. John looks up the nutrient composition of two of his favorite fast-food meals (see table).

▼

If John chooses the Big Mac, fries, and soda, for lunch, how many micrograms of vitamin A would he be consuming? (*Hint:* You first need to convert % Daily Value to micrograms of vitamin A.)

		ENERGY (kcal)	VITAMIN A (% Daily Value)
McDonald's	Big Mac	540	6
	Medium fries	380	0.2
	Soda (20 oz)	240	0
KFC	Fried chicken thigh and breast	690	2.6
	Mashed potatoes and gravy	120	1.5
	Soda (20 oz)	240	0

▼

For dinner, John has 2 cups of spaghetti with meat sauce, a slice of Italian bread with 1 tsp butter, and a cup of 1% milk. How much vitamin A does this provide?

Hywit Dimyadi/iStockphoto

▼

If John has the McDonald's meal for lunch and the spaghetti for dinner, how much more vitamin A does he need to meet the RDA?

CRITICAL THINKING QUESTIONS

- **John needs 2500 kcal to maintain his weight. Assuming he has the McDonald's meal for lunch and the spaghetti for dinner, plan a breakfast that would provide the additional calories and vitamin A needed to meet his needs for the day.**
- **Do you think John is meeting his RDA for the other fat-soluble vitamins? Why or why not?**

iProfile Use iProfile to find out how much vitamin A is in your favorite fast-food meal.

Mild vitamin A deficiency causes night blindness, which is a reversible condition. If the deficiency progresses, the ability to maintain epithelial tissue is impaired, particularly in the eye, and immune function, growth, and reproduction become affected. Children deficient in vitamin A have poor appetites; are anemic; have an increased susceptibility to infections, including measles; and are more likely to die in childhood.

Why Vitamin A Deficiency Can Cause Blindness When vitamin A is deficient, epithelial cells do not differentiate normally because vitamin A is not there to turn on or turn off the production of particular proteins. For example, the epithelial tissue on many body surfaces contains cells that produce mucus for lubrication. When mucus-secreting cells die, new cells normally differentiate into mucus-secreting cells to replace them. When vitamin A is deficient, the new cells do not differentiate properly and instead become cells that produce a protein called **keratin** (Figure 9.6A). Keratin is the hard protein that makes up hair and fingernails. As the mucus-secreting cells die and are replaced by keratin-producing cells, the epithelial surface becomes hard and dry. This process is known as *keratinization*. The hard, dry surface does not have the protective capabilities of normal epithelium and so the likelihood of infection is increased. The risk of infection is compounded by the fact that vitamin A deficiency also decreases immune function.

keratin A hard protein that makes up hair and nails.

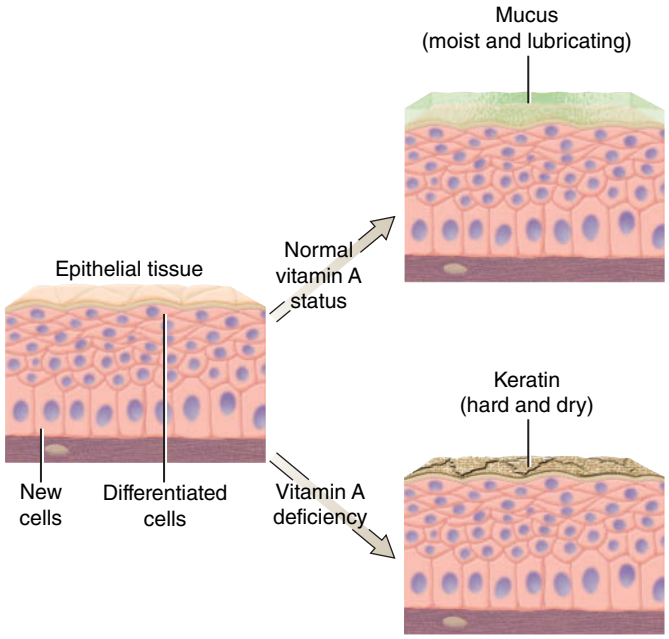
All epithelial tissues are affected by vitamin A deficiency, but the eye is particularly susceptible to damage. The mucus in the eye normally provides lubrication, washes away dirt and other particles, and also contains a protein that helps destroy bacteria. When vitamin A is deficient, the lack of mucus and the buildup of keratin cause the cornea to dry and crack, leaving the eye open to infection. A spectrum of eye disorders, known as **xerophthalmia**, is associated with vitamin A deficiency. Xerophthalmia begins as night blindness and extreme dryness and progresses to wrinkling, cloudiness, and softening of the cornea, called **keratomalacia**. If left untreated, it can result in rupture of the cornea, infection, degenerative tissue changes, and permanent blindness (Figure 9.6B).

xerophthalmia A spectrum of eye conditions resulting from vitamin A deficiency that may lead to blindness. An early symptom is night blindness, and as deficiency worsens, lack of mucus leaves the eye dry and vulnerable to cracking and infection.

keratomalacia Softening, drying, and ulceration of the cornea resulting from vitamin A deficiency.

How Vitamin A Deficiency Affects Immune Function, Reproduction, and Growth In the immune system, vitamin A is needed for the differentiation that produces the different types of immune cells. Vitamin A deficiency also reduces the function of specific immune cells and hinders the normal regeneration of mucosal barriers damaged by infection.[18] This impaired immune function increases the risk of illness and infection due to defective epithelial tissue barriers (see Chapter 18, *Science Applied: Vitamin A: The Anti-Infective Vitamin*).

FIGURE 9.6 Vitamin A deficiency and xerophthalmia



A. When vitamin A is deficient, immature cells cannot differentiate normally, and instead of mucus-secreting cells, they become cells that produce keratin.

B. As xerophthalmia progresses, the drying of the cornea results in ulceration, infection, and ultimately blindness.

ISM/Phototake

During reproduction, vitamin A is needed to direct cells to differentiate and to form the shapes and patterns needed for the development of a complete organism. Lack of vitamin A during embryonic development results in abnormalities and death. Poor overall growth is an early sign of vitamin A deficiency in children. In growing children, vitamin A affects the activity of cells that form and break down bone, and a deficiency early in life can cause abnormal jawbone growth, resulting in crooked teeth and poor dental health.

Recommended Vitamin A Intake

The recommended intake for vitamin A is based on the amount needed to maintain normal body stores. The RDA is set at 900 μg of vitamin A per day for men and 700 μg/day for women.[4] The RDA is increased in pregnancy to account for the vitamin A that is transferred to the fetus and during lactation to account for the vitamin A lost in milk. The RDA for children is set lower than that for adults based on their smaller body size. For infants, an AI has been set based on the amount of vitamin A consumed by an average healthy breastfed infant.

Recommendations for vitamin A intake are expressed in micrograms (μg) of retinol. Retinol can be supplied by both preformed vitamin A and carotenoids in the diet. No quantitative recommendations have been made for intakes of β-carotene or other carotenoids. Their intake is considered only with regard to the amount of retinol they provide. Because carotenoids are less well absorbed and not completely converted to vitamin A, a correction factor, referred to as **retinol activity equivalents (RAEs)**, must be applied to carotenoids to determine the amount of usable vitamin A they provide. Twelve micrograms of β-carotene provide 1 RAE of vitamin A, and 24 μg of α-carotene or β-cryptoxanthin provide 1 RAE.[4]

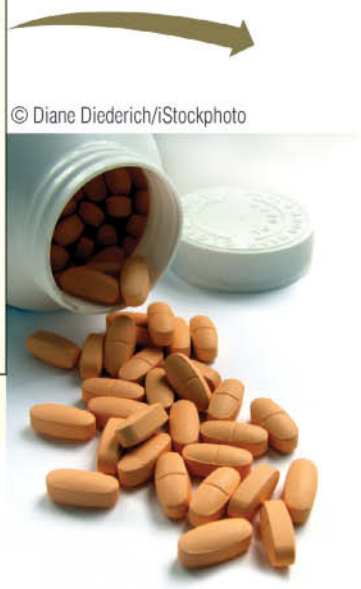
retinol activity equivalent (RAE) The amount of retinol, β-carotene, α-carotene, or β-cryptoxanthin that provides vitamin A activity equal to 1 μg of retinol.

As our understanding of vitamin A has increased, the units in which recommended intakes have been expressed have changed. Prior to 1980, vitamin A was expressed in International Units (IUs). The 1989 RDAs used values called retinol equivalents (REs) to account for differences in absorption between preformed vitamin A and carotenoids. These older units are still found in some food-composition databases and tables. Values for converting REs and IUs to micrograms of retinol are given in Figure 9.7.

Supplement Facts
Serving Size 1 Tablet

	Amount Per Serving	% Daily Value
Vitamin A (as retinyl acetate and 50% as beta-carotene)	5000 IU	100%
Vitamin C (as ascorbic acid)	60 mg	100%
Vitamin D (as cholecalciferol)	400 IU	100%
Vitamin E (as dl-alpha tocopheryl acetate)	30 IU	100%
Thiamin (as thiamin mononitrate)	1.5 mg	100%
Riboflavin	1.7 mg	100%
Niacin (as niacinamide)	20 mg	100%
Vitamin B_6 (as pyridoxine hydrochloride)	2.0 mg	100%
Folate (as folic acid)	400 mcg	100%
Vitamin B_{12} (as cyanocobalamin)	6 mcg	100%
Biotin	30 mcg	10%
Pantothenic Acid (as calcium pantothenate)	10 mg	100%

Other ingredients: Gelatin, lactose, magnesium stearate, microcrystalline cellulose, FD&C Yellow No. 6, propylene glycol, propylparaben, and sodium benzoate.



Converting Vitamin A Units

Form and source	Amount equal to 1 μg retinol
Preformed vitamin A in food or supplements	1 μg 1 RAE 1 μg RE 3.3 IU
β-Carotene in food[a]	12 μg 1 RAE 2 μg RE 20 IU
α-Carotene or β-cryptoxanthin in food	24 μg 1 RAE 2 μg RE 40 IU

[a] β-Carotene in supplements may be better absorbed than β-carotene in food and so provides more vitamin A activity. It is estimated that 2 μg of β-carotene dissolved in oil provides 1 μg of vitamin A activity.

FIGURE 9.7 How much retinol is in your supplement?
The Supplement Facts panel on dietary supplements list the amounts of vitamin A and other fat-soluble vitamins in IUs. The information in the table can be used to convert the amount of vitamin A provided by your supplement or other vitamin A sources to micrograms of retinol.

THINK CRITICALLY

Why is liver from any animal particularly high in vitamin A?

FIGURE 9.8 High doses of vitamin A and carotenoids

Paul Nicklen/NG Image Collection

A. Foods generally do not naturally contain large enough amounts of nutrients to be toxic. Polar bear liver is an exception. It contains about 100,000 μg of vitamin A in just 1 oz and has caused vitamin A toxicity in Arctic explorers who consumed it.

From A. Mazzone and A.Dal Canton, The New England Journal of Medicine, 2002; 347-222-223

B. The hand on the right illustrates hypercarotenemia, the harmless buildup of carotenoids in the adipose tissue that makes the skin look yellow-orange. The color is particularly apparent on the palms of the hands and the soles of the feet.

Vitamin A Toxicity and Supplements

Preformed vitamin A is absorbed rapidly and eliminated from the body slowly. Therefore, toxicity can result acutely from a high dose in a short period of time or chronically from lower intake over a longer period of time. Acute toxicity causes symptoms such as nausea, vomiting, headache, dizziness, blurred vision, and a lack of muscle coordination. It has been reported in Arctic explorers who consumed polar bear liver (Figure 9.8A). Polar bear liver is not a common dish at most dinner tables, but supplements of preformed vitamin A also have the potential to deliver a toxic dose. Chronic toxicity occurs when preformed vitamin A doses as low as 10 times the RDA are consumed for a period of months to years. The symptoms of chronic toxicity include weight loss, muscle and joint pain, liver damage, osteoporosis and bone fractures, visual defects, dry scaling lips, and skin rashes.[19,20]

LIFE CYCLE

Excess vitamin A is a particular concern for pregnant women because it may contribute to birth defects.[4,21] The UL is set at 2800 μg/day of preformed vitamin A for 14- to 18-year-olds and 3000 μg/day for adults.

Carotenoid Toxicity Because of the toxicity of preformed vitamin A, most supplements provide some or all of their vitamin A as carotenoids (Table 9.1). Carotenoids are not toxic because their absorption from the diet decreases at high doses, and once in the body, their conversion to retinoids is limited. Large daily intakes of carotenoids—usually from carrot juice or β-carotene

TABLE 9.1 Benefits and Risks of Fat-Soluble Vitamin Supplements

Supplement	Marketing claim	Actual benefits or risks
Vitamin A (retinoids)	Improves vision; prevents skin disorders; enhances immunity.	Needed for vision and eye health, growth, reproduction, and immunity, but extra as supplements does not provide additional benefits. Toxic at high doses, can cause birth defects and bone loss.
Carotenoids	Needed for vision; prevents skin disorders; antioxidant.	Can provide all functions of vitamin A and is an antioxidant, but supplements do not provide additional benefits. High doses can cause orange-colored skin and increase lung cancer risk in smokers.
Vitamin D	Bone health; reduces the risk of multiple sclerosis.	Needed for calcium absorption and bone maintenance. There is evidence that supplements reduce the risk of autoimmune diseases and cancer. High doses cause heart and kidney damage.
Vitamin E	Prevents heart disease; improves symptoms of fibrocystic breast disease; promotes immune function; reduces scar formation.	Antioxidant, protects cell membranes; little evidence that oral supplements reduce risk of heart disease or that topical application reduces scar formation. High doses interfere with anticoagulant medications.
Vitamin K	Improves blood clotting, increases bone density and prevents osteoporosis, protects against heart disease and cancer.	Needed for normal blood clotting. Adequate vitamin K is needed for bone health and reduces death from heart disease and cancer but supplements do not provide additional benefits. Interferes with blood thinning medications. High doses may cause anemia and brain or liver damage.

supplements—do, however, lead to a condition known as **hypercarotenemia**. In this condition, large amounts of carotenoids stored in the adipose tissue give the skin a yellow-orange color (Figure 9.8B). It is not known to be dangerous, and when intake decreases, the skin returns to its normal color.

hypercarotenemia A condition in which carotenoids accumulate in the adipose tissue, causing the skin to appear yellow-orange.

Carotenoid supplements are generally nontoxic and can be used to prevent vitamin A deficiency, but there is concern that large amounts may be harmful to cigarette smokers. A number of human intervention trials found an increased incidence of lung cancer in cigarette smokers who took β-carotene supplements.[22] Not all trials have demonstrated this effect, but smokers are advised to avoid β-carotene supplements and to rely on food sources to obtain carotenoids in their diet. The small amounts found in standard-strength multivitamin supplements are not likely to be harmful for any group. No UL has been determined for carotenoid intake.

Vitamin A as a Drug Derivatives of vitamin A are currently used as drugs. One derivative of retinoic acid, marketed as Retin-A, is used topically to treat acne and to reduce wrinkles due to sun damage. It acts by increasing the turnover of cells. In patients with acne, new cells replace the cells of existing pimples and the rapid turnover of cells prevents new pimples from forming. By a similar mechanism, Retin-A can reduce wrinkles and diminish areas of darkened skin and rough skin. Another vitamin A derivative, 13-*cis*-retinoic acid, marketed as Accutane, is taken orally to treat acne. This medication can have serious side effects, including dry itchy skin and chapped lips, irritated eyes, joint and muscle pain, decreased night vision, depression, and increases in blood lipid levels. In pregnant women, it can cause severe birth defects, including brain damage and physical malformations. Although Retin-A and Accutane are derivatives of vitamin A, they are drugs. Vitamin A supplements cannot be substituted as a treatment for acne, and large doses will cause toxicity symptoms.

9.4 Vitamin D

LEARNING OBJECTIVES

- Explain why vitamin D is known as the "sunshine vitamin."
- Relate the functions of vitamin D to the symptoms that occur when it is deficient.
- Discuss why vitamin D deficiency is on the rise.

Vitamin D is known as the "sunshine vitamin" because it can be produced in the skin by exposure to ultraviolet light. Because vitamin D can be made in the body, there is a long-standing debate on whether vitamin D is a vitamin or a hormone. By definition, vitamins are dietary essentials. However, vitamin D can be formed in the skin, so it is essential in the diet only when exposure to sunlight is limited or the body's ability to synthesize the vitamin is reduced. Vitamin D acts like a hormone because it is produced in one organ, the skin, and affects other organs, primarily the intestine, bone, and kidney.

Vitamin D in the Diet

The major source of vitamin D for most humans is exposure to sunlight.[23] Only a few foods are natural sources of vitamin D. These include liver; fatty fish, such as salmon, mackerel, and sardines; cod-liver oil; and egg yolks (Figure 9.9). These foods contain **cholecalciferol**, also known as vitamin D_3. Vitamin D–fortified foods, such as fortified milk and breakfast cereals, are important sources of vitamin D in the United States. These may contain vitamin D_3 or another active form of the vitamin called *ergocalciferol*, or vitamin D_2.

cholecalciferol The chemical name for vitamin D_3. It can be formed in the skin of animals by the action of sunlight on 7-dehydrocholesterol.

How Vitamin D Functions in the Body

When sunlight strikes the skin, a compound made from cholesterol, called *7-dehydrocholesterol*, is converted to cholecalciferol (vitamin D_3). Regardless of whether the vitamin D in your

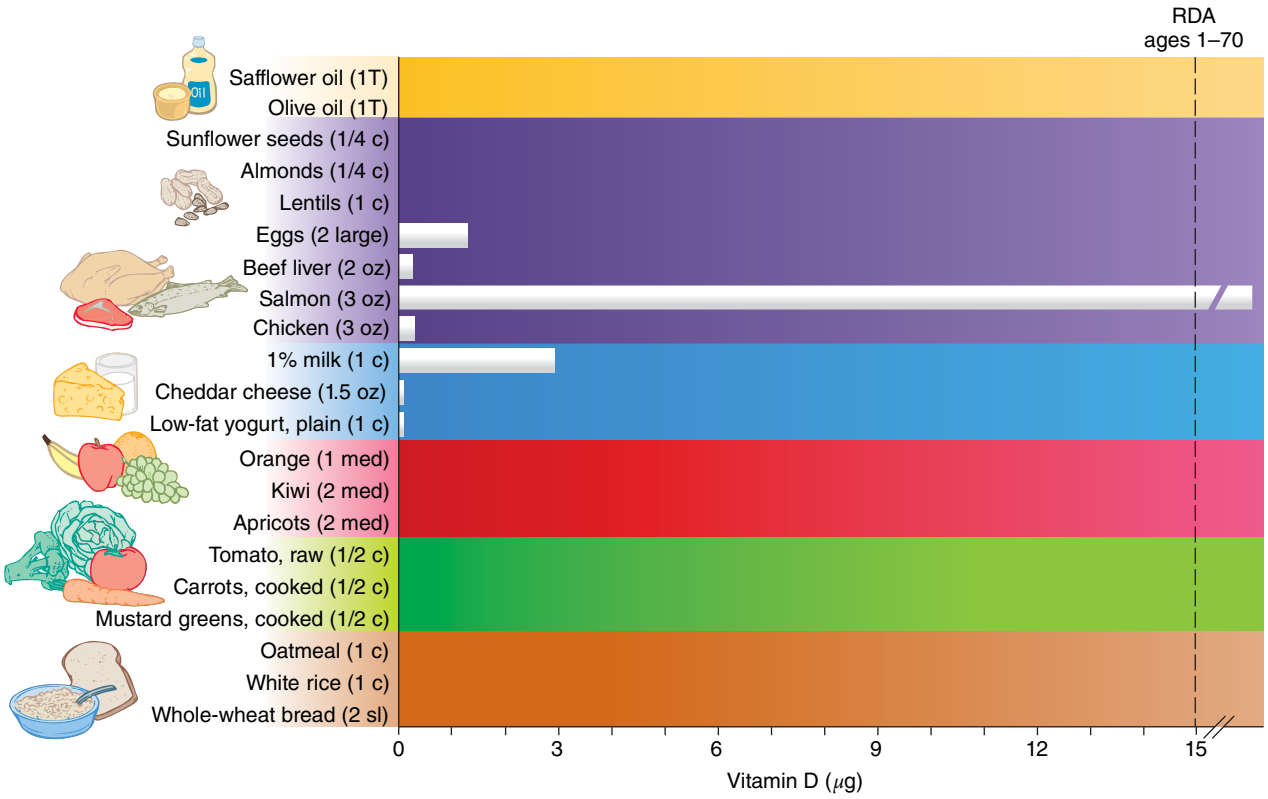


FIGURE 9.9 Vitamin D content of MyPlate food groups
Only a few foods are natural sources of vitamin D; the dashed line shows the RDA for people ages 1 to 70.

body was synthesized in your skin or consumed in your diet, it is inactive until it is chemically altered in the liver and then the kidney. In the liver, a hydroxyl group (OH) is added to vitamin D to form 25-hydroxy vitamin D_3. This is the form of the vitamin that circulates in the blood and is monitored in the blood as an indicator of patients' vitamin D status. However, 25-hydroxy vitamin D_3 is inactive and must be modified by the kidney, where another hydroxyl group is added to make the active form of vitamin D: 1,25-dihydroxy vitamin D_3 (Figure 9.10).

Metabolism

parathyroid hormone (PTH) A hormone released by the parathyroid gland that acts to increase blood calcium levels.

Why Vitamin D Is Needed for Healthy Bones The principal function of vitamin D is to maintain levels of calcium and phosphorus in the blood that favor bone mineralization. When blood calcium levels drop too low, the parathyroid gland releases **parathyroid hormone (PTH)**. PTH stimulates enzymes in the kidney to convert 25-hydroxy vitamin D_3 to the active form of the vitamin. Active vitamin D enters the blood and travels to its major target tissues—intestine, bone, and kidney—where it acts to increase calcium levels in the blood. The functions of vitamin D, like those of vitamin A, are due to its role in gene expression. The active form of vitamin D is believed to regulate directly and indirectly the expression of up to 2000 genes.[24] Active vitamin D binds to vitamin D receptor proteins in the nucleus of cells in target tissues and increases the production of certain proteins (see Figure 9.5). Its effect at three different tissues helps to increase blood calcium levels.[25] One target is intestinal cells, where vitamin D increases the expression of genes that code for the production of intestinal calcium channel and calcium binding proteins.[24] These proteins are needed for the active transport of dietary calcium from the intestinal lumen into the body. This action requires only very low levels of the active vitamin. If dietary calcium is unavailable, higher levels of vitamin D act at the bone and kidney in conjunction with PTH to return blood calcium to normal. At the bone, vitamin D causes precursor cells to differentiate into cells that break down bone. Bone breakdown releases calcium into the blood. At the

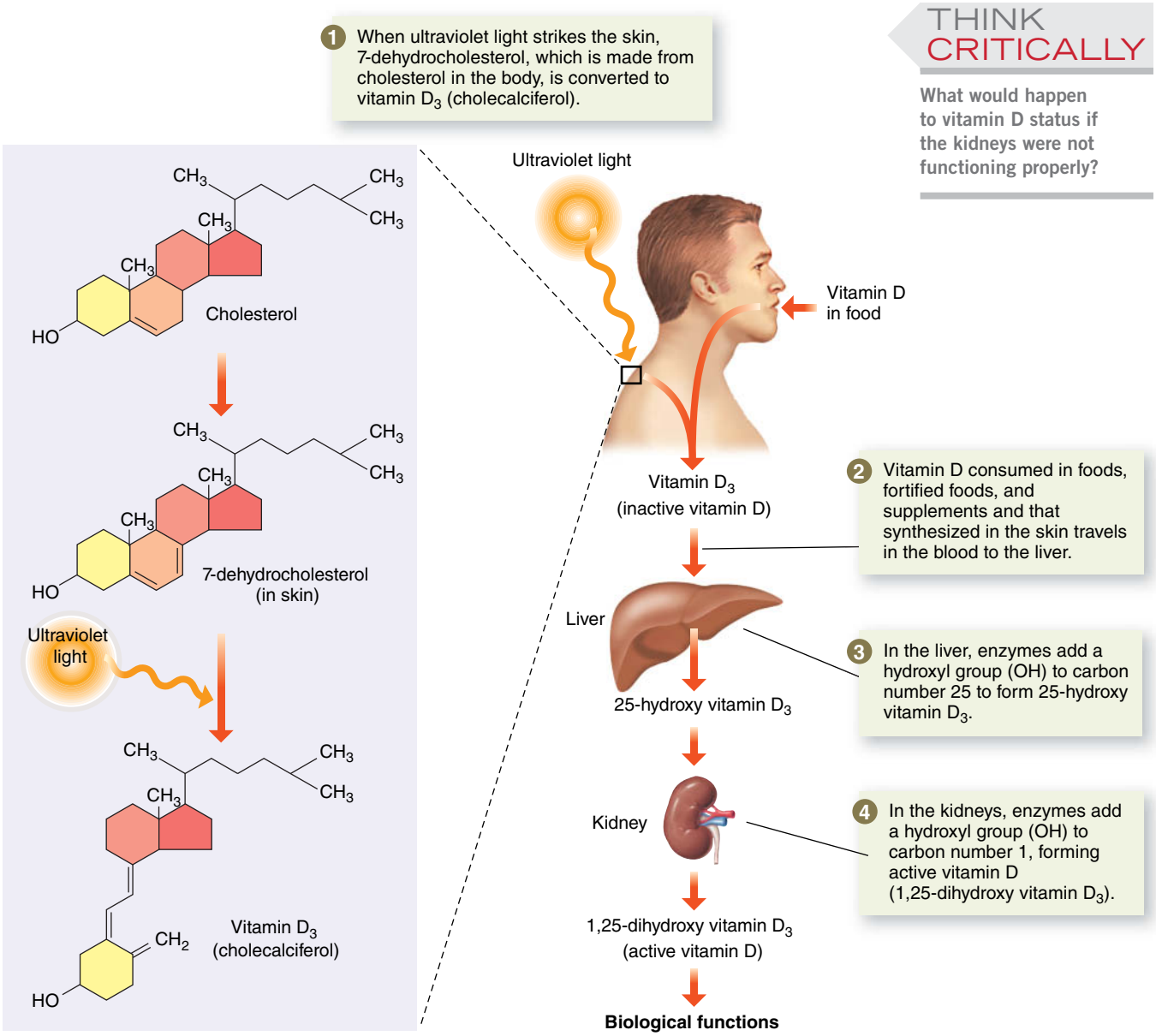


FIGURE 9.10 Vitamin D synthesis and activation
In order to function, vitamin D from food and from synthesis in the skin must be activated by first the liver and then the kidneys.

kidney, vitamin D acts with PTH to increase the amount of calcium retained by the kidneys (Figure 9.11).[25]

Vitamin D also regulates levels of phosphorus in the blood. The mechanisms are not as clearly understood, but the result is levels of calcium and phosphorus that favor bone mineralization.

Other Functions of Vitamin D Vitamin D receptor proteins have been found in over 35 tissues that are not involved in bone metabolism, including endothelial cells, cells of the pancreas, heart and skeletal muscle cells, and cells of the immune system.[26] Adequate levels of vitamin D in these tissues help protect health. Vitamin D is hypothesized to protect against cancer by decreasing the proliferation of cancer cells, promoting cancer cell death, and inhibiting the spread of cancerous cells. There is also evidence that vitamin D protects against cardiovascular disease, type 2 diabetes, and infectious disease, as well as autoimmune disorders such as type 1 diabetes, multiple sclerosis, and rheumatoid arthritis.[24]

THINK CRITICALLY

Why is vitamin D included in many calcium supplements?

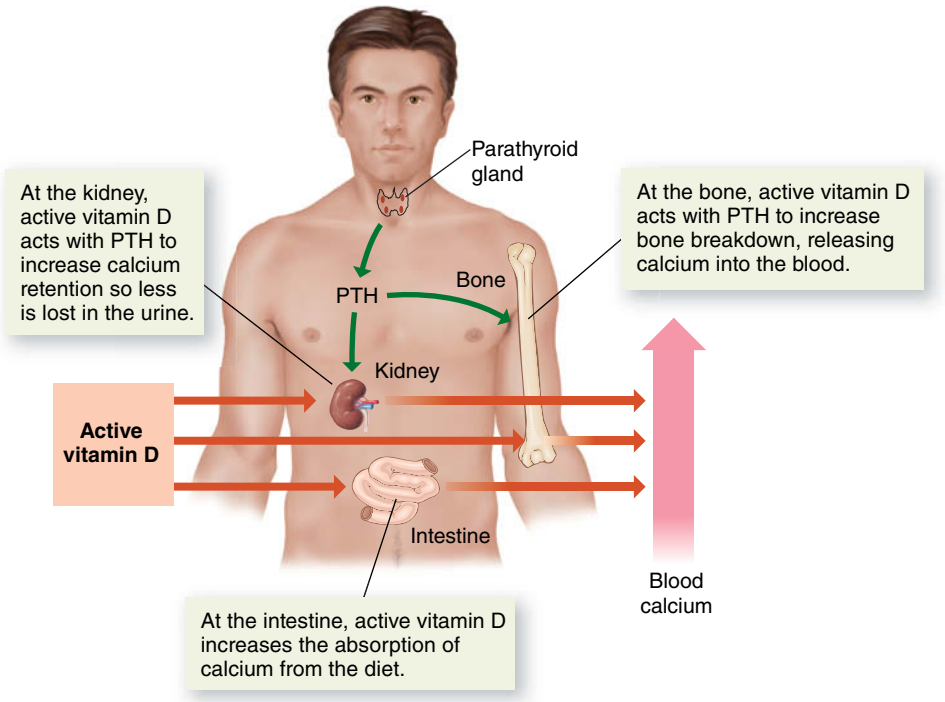


FIGURE 9.11 Functions of vitamin D
The actions of vitamin D help to maintain normal levels of blood calcium.

rickets A vitamin D deficiency disease in children that is characterized by poor bone development because of inadequate calcium absorption.

Vitamin D Deficiency

Low blood levels of vitamin D are now believed to play an important role in the development of many chronic diseases, including multiple sclerosis, type 1 diabetes, inflammatory bowel disease, infections, cardiovascular disease, cancer, and even neurological disorders such as Alzheimer's disease.[26] More severe vitamin D deficiency interferes with calcium absorption; when vitamin D is deficient, only about 10 to 15% of the calcium in the diet can be absorbed. As a result, calcium is not available for proper bone mineralization, and abnormalities in bone structure occur.

In children, vitamin D deficiency causes **rickets**. Rickets is characterized by weak bones due to inadequate calcium and phosphorus, and bone deformities such as narrow rib cages, known as pigeon breasts, and bowed legs (Figure 9.12). Vitamin D deficiency also reduces bone mass, causes muscle pain and weakness, and prevents children from reaching their genetically programmed height. Rickets, first recognized in the 1600s, was common during the Industrial Revolution when large numbers of poorly nourished children lived under a layer of smog in the newly industrialized cities. Tall buildings and smog-filled air reduced children's exposure to sunlight. Today, the risk of vitamin D deficiency is increased by having dark skin pigmentation, which prevents UV light rays from penetrating into the layers of the skin where vitamin D is formed, and by using sunscreen, wearing concealing clothing, living in cities with pollution and tall buildings, working and playing indoors, and living too far north or south of the equator, all of which reduce the amount of sunlight that reaches the skin (Figure 9.13).

Biophoto Associates/Photo Researchers

FIGURE 9.12 Rickets
The vitamin D deficiency disease rickets causes short stature and bone deformities. The characteristic bowed legs occur because the bones are too weak to support the weight of the body.

The fortification of milk with vitamin D has helped greatly to reduce rickets in the United States, but it is still a problem in infants and young children with dark skin, which reduces the formation of vitamin D, and those who are breast-fed because breast milk is low in vitamin D.[2] Rickets is also seen in children with disorders that affect fat absorption and in children who for any number of reasons do not drink milk.

In adults, vitamin D deficiency causes a condition called **osteomalacia**. Because bone growth is complete in adults, osteomalacia does not cause bone deformities, but bones are weakened because not enough calcium is available to form the mineral deposits needed to maintain their health. Insufficient bone mineralization leads to fractures of the weight-bearing bones such as those in the hips and spine. In older adults, vitamin D deficiency is associated with an increased risk of falls, further contributing to fracture risk.[26] Osteomalacia also causes bone pain and muscle aches and weakness. It can precipitate or exacerbate osteoporosis, which is a loss of total bone mass, not just minerals (see Chapter 11).

FIGURE 9.13 Sun exposure affects vitamin D synthesis

NG Maps

A. The angle at which the sun strikes the earth affects the amount of UV radiation and, hence, the body's ability to synthesize vitamin D in the skin. During the winter at latitudes greater than about 40 degrees north or south, there is not enough UV radiation to synthesize adequate amounts.

© Studio-Annika/iStockphoto

B. Sunscreen with an SPF of 15 decreases vitamin D synthesis by more than 95%.[27] Sunscreen is important for reducing the risk of skin cancer, but some time in the sun without sunscreen may be needed to meet vitamin D needs.

© Robert Harding Picture Library Ltd/Alamy Limited

C. Dark skin pigmentation may reduce the body's ability to make vitamin D in the skin by as much as 99%. Concealing clothing worn by certain cultural and religious groups prevents sunlight from striking the skin. This explains why vitamin D deficiency occurs in women and children in some of the sunniest regions of the world.

Osteomalacia is common in adults with kidney failure because the conversion of vitamin D from the inactive to active form is reduced. African Americans are at particular risk for vitamin D deficiency because vitamin D synthesis is low due to dark skin pigmentation and consumption of milk fortified with vitamin D is low due to the high frequency of lactose intolerance. The elderly are at risk because the ability to synthesize vitamin D in the skin decreases with age and because older adults typically cover more of their skin with clothing and spend less time in the sun than their younger counterparts. In addition, the elderly tend to have a lower intake of dairy products.

osteomalacia A vitamin D deficiency disease in adults characterized by a loss of minerals from bones. It causes bone pain, muscle aches, and an increase in bone fractures.

Recommended Vitamin D Intake

Recommended intakes for vitamin D are expressed both in IUs and in micrograms. One IU is equal to 0.025 μg of vitamin D (40 IU = 1 μg of vitamin D). The RDA for vitamin D for children, adults ages 70 and under, and pregnant and lactating women is set at 600 IU or 15 μg/day—an amount that ensures vitamin D levels in the blood are high enough to support bone health even when sun exposure is minimal.[25] Due to physiological changes with aging, such as a reduction in vitamin D activation at the kidney and less efficient vitamin D synthesis in the skin, the amount of vitamin D needed to reduce the risk of fractures is higher in older adults. The RDA for adults older than age 70 is 800 IU (20 μg)/day. Data are not sufficient to establish an EAR for infants less than 1 year of age, and therefore an AI has been developed. The AI for infants 0 to 12 months is set at 400 IU (10 μg) of vitamin D per day.

LIFE CYCLE

VIDEO

Meeting Vitamin D Needs

Because vitamin D is not widespread in the diet and exposure to sunlight is inconsistent, many people are at risk for vitamin D deficiency. To meet needs, supplements containing vitamin D are recommended to vulnerable groups.

Meeting Needs with Food and Sunlight Milk is a good source of vitamin D, but if you synthesized no vitamin D in your skin, you would need to drink 5 cups of vitamin D–fortified milk per day to obtain the RDA for vitamin D. Salmon and other fatty fish are also good sources—3 oz will provide the RDA.

The recommended intakes for vitamin D are based on the assumption of minimal sun exposure. This assumption is made because of the variation in the extent to which synthesis from sunlight meets the requirement. The amount of vitamin D synthesized in the skin is affected by many variables, so it is not possible to make a single recommendation on the amount of time people need to spend in the sun to meet their vitamin D needs. For example, during the spring, summer, and fall, light-skinned individuals may need to spend only 5 to 10 minutes outdoors, two to three times a week, with their faces, hands, arms, and legs exposed to meet their vitamin D requirement, whereas very dark-skinned individuals (who rarely sunburn) may need 10 to 50 times more sun exposure to produce the same amount of vitamin D.[28,29] In the summer, children and active adults usually spend enough time outdoors without sunscreens to provide their vitamin D requirement. It has been estimated that more than 90% of the vitamin D requirement for most people comes from casual exposure to sunlight.[30]

When Is Supplemental Vitamin D Recommended? Many people in the United States and around the world have low blood levels of vitamin D because they do not consume enough dietary vitamin D or get enough sun exposure to meet their needs.[31] In the United States, it is estimated that adults 20 years of age and older consume only 4.6 μg/day and children 2 to 19 consume only 6.0 μg/day, amounts well below the RDA of 15 μg/day.[25] Many of these people may meet their need through sun exposure, but those who don't would benefit from supplemental vitamin D.

Vitamin D supplements are specifically recommended for a number of vulnerable groups. Because breast milk is low in vitamin D, it is recommended that breast-fed and partially breast-fed infants be supplemented with 400 IU (10 μg)/day of vitamin D beginning in the first few days of life and continuing until they are consuming about 1 L (4 cups) of vitamin D–fortified formula or milk daily.[32,33] Supplemental vitamin D is also recommended for all non–breast-fed infants who are ingesting less than 4 cups per day of vitamin D–fortified formula or milk and for children and adolescents who do not get regular sunlight exposure and do not ingest at least 4 cups per day of vitamin D–fortified milk. Other groups that might benefit from vitamin D supplements include people who do not drink milk or consume dairy products (see Chapter 6), older adults (see Chapter 16), individuals with dark skin pigmentation, individuals who do not absorb fat normally, and individuals with limited sun exposure because they are homebound, wear robes and head coverings for religious reasons, or work in occupations that prevent sun exposure.[34]

Individuals who are obese may also benefit from vitamin D supplementation. Compared to nonobese individuals, those with a body mass index $\geq$ 30 kg/m^2 have lower vitamin D levels. This is believed to be because the greater amounts of subcutaneous fat sequester more of the vitamin D and reduce its release into the blood.[24]

Vitamin D Toxicity

Too much vitamin D in the body can cause high calcium concentrations in the blood and urine, deposition of calcium in soft tissues such as the blood vessels and kidneys, and cardiovascular damage. Synthesis of vitamin D from exposure to sunlight does not produce toxic amounts because the body regulates vitamin D formation. Consumption of unfortified foods is also not a concern, but oversupplementation and overfortification can pose a risk. One case of accidental overfortification of milk resulted in the hospitalization of 56 individuals and the deaths of 2.[35] The UL for ages 9 and older for vitamin D is 4000 IU (100 μg)/day.[25]

9.5 Vitamin E

LEARNING OBJECTIVES

- List two food sources of vitamin E.
- Explain the function of vitamin E.

Vitamin E is a fat-soluble vitamin with an antioxidant function. It was first identified as a fat-soluble component of grains that was necessary for fertility in laboratory rats. It took almost 30 years to isolate this vitamin and to determine that it is also necessary for reproduction in humans. The chemical name for vitamin E, **tocopherol**, is from the Greek *tokos*, meaning "childbirth," and *phero*, meaning "to bring forth." Although vitamin E has been promoted to slow aging, cure infertility, reduce scarring, and protect against air pollution, research has not shown it to be useful for these purposes. Today we continue to explore the role of this antioxidant in protecting us from chronic disease.

tocopherol The chemical name for vitamin E.

Vitamin E in the Diet

Several naturally occurring forms of vitamin E are found in foods, but only the **alpha-tocopherol (α-tocopherol)** form can meet vitamin E requirements in humans. The other forms do not meet vitamin E needs because they are not converted to α-tocopherol in humans and cannot be transported by the α-tocopherol transfer protein, a liver protein that helps distribute vitamin E to body tissues.

alpha-tocopherol (α-tocopherol) The form of tocopherol that provides vitamin E activity in humans.

Dietary sources of vitamin E include nuts, seeds, and peanuts; plant oils, such as soybean, corn, and sunflower oils; leafy green vegetables; and wheat germ (Figure 9.14). Vitamin E is also consumed in fortified foods, such as breakfast cereals, and supplements; however, the vitamin E from these sources may not be as efficient at meeting needs. The synthetic form of α-tocopherol found in dietary supplements and fortified foods is composed of eight different **isomers**. Only

isomers Molecules with the same molecular formula but a different arrangement of the atoms.

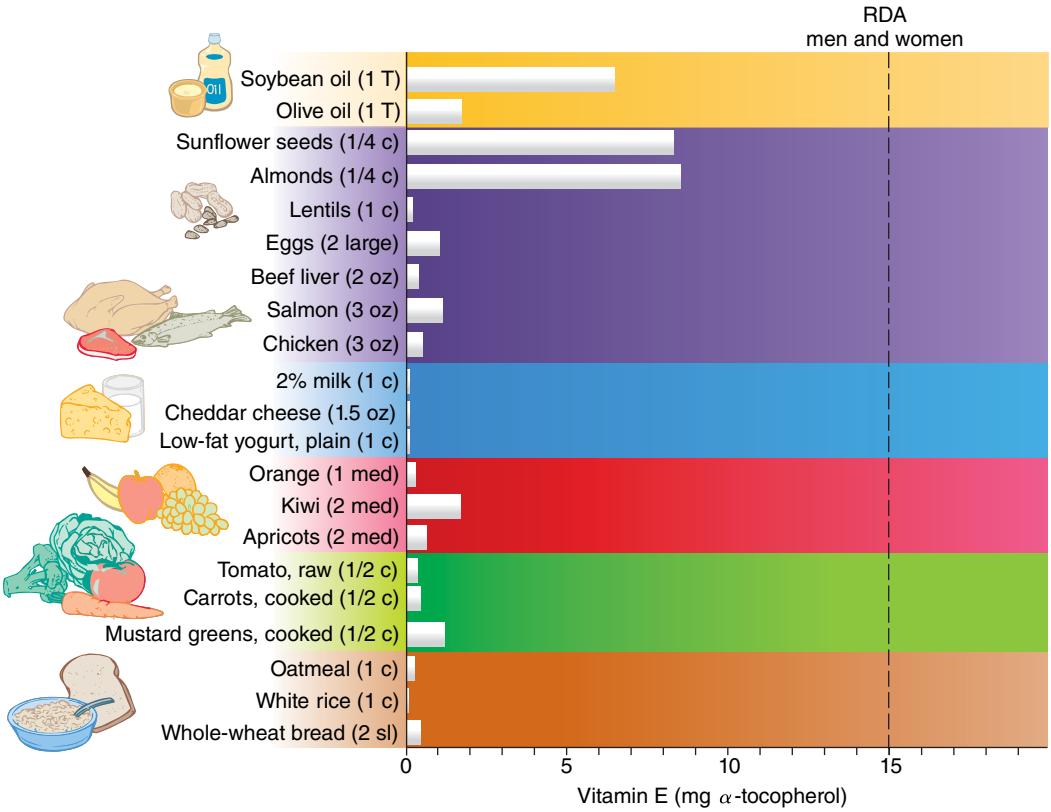


FIGURE 9.14 Vitamin E content of MyPlate food groups
Adults can obtain their RDA for vitamin E (dashed line) by consuming plant oils, nuts and seeds, and leafy green vegetables.

Supplement Facts

Serving Size 1 Tablet

	Amount Per Serving	% Daily Value
Vitamin A (as retinyl acetate and 50% as beta-carotene)	5000 IU	100%
Vitamin C (as ascorbic acid)	60 mg	100%
Vitamin D (as cholecalciferol)	400 IU	100%
Vitamin E (as dl-alpha tocopheryl acetate)	30 IU	100%
Thiamin (as thiamin mononitrate)	1.5 mg	100%
Riboflavin	1.7 mg	100%
Niacin (as niacinamide)	20 mg	100%
Vitamin B_6 (as pyridoxine hydrochloride)	2.0 mg	100%
Folate (as folic acid)	400 mcg	100%
Vitamin B_{12} (as cyanocobalamin)	6 mcg	100%
Biotin	30 mcg	10%
Pantothenic Acid (as calcium pantothenate)	10 mg	100%

Other ingredients: Gelatin, lactose, magnesium stearate, microcrystalline cellulose, FD&C Yellow No. 6, propylene glycol, propylparaben, and sodium benzoate.

Converting Vitamin E Units

To estimate the α-tocopherol intake from foods:

- If values are given as mg α-TEs:
  mg α-TE $\times$ 0.8 = mg α-tocopherol
- If values are given as IUs:
  First, determine if the source of the α-tocopherol is natural or synthetic.
  - For natural α-tocopherol:
    IU of natural α-tocopherol $\times$ 0.67 = mg α-tocopherol
  - For synthetic α-tocopherol (dl-α-tocopherol):
    IU of synthetic α-tocopherol $\times$ 0.45 = mg α-tocopherol

© Diane Diederich/iStockphoto

FIGURE 9.15 How much vitamin E is in your supplement?
The Supplement Facts panel on dietary supplements lists the amounts of vitamin E and other fat-soluble vitamins in IUs. The amount of vitamin E provided by your supplement can be converted to milligrams of α-tocopherol using the equations shown in the table.

half of these are active in the body. Therefore, synthetic α-tocopherol provides half of the biological activity of natural α-tocopherol; 10 mg of synthetic α-tocopherol provides the function of 5 mg of natural α-tocopherol.

Because the discovery that only the α-tocopherol form of vitamin E provides activity is relatively recent, most nutrient databases and nutrition labels overrepresent the amount of functional vitamin E in foods. Previously, all forms of tocopherol were included when calculating vitamin E content. Vitamin E content was expressed as either IUs, defined as 1 mg of synthetic α-tocopherol, or α-tocopherol equivalents (α-TEs), which considered other tocopherols as fractions of α-tocopherol. To correct for this, formulas have been developed to convert IUs and α-TEs into milligrams of α-tocopherol (Figure 9.15).

Because vitamin E is sensitive to destruction by oxygen, metals, light, and heat, some is lost during food processing, cooking, and storage. Although it is relatively stable at normal cooking temperatures, the vitamin E in cooking oils may be destroyed if the oil is repeatedly heated to the high temperatures used for deep-fat frying.

How Vitamin E Functions in the Body

Vitamin E absorption depends on normal fat absorption. Once absorbed, vitamin E is incorporated into chylomicrons. As chylomicrons are broken down, some vitamin E is distributed to other lipoproteins and delivered to tissues, but most is taken to the liver where, with the help of α-tocopherol transfer protein, the α-tocopherol form is incorporated into very-low-density lipoproteins (VLDLs).[36] The α-tocopherol in VLDLs is distributed to other plasma lipoproteins and delivered to cells.

Vitamin E functions primarily as a fat-soluble antioxidant. It neutralizes reactive oxygen compounds before they damage unsaturated fatty acids in cell membranes. After vitamin E is used to eliminate free radicals, its antioxidant function can be restored by vitamin C (Figure 9.16). Because polyunsaturated fats are particularly susceptible to oxidative damage, vitamin E needs increase as polyunsaturated fat intake increases.

By protecting cell membranes, vitamin E is important in maintaining the integrity of red blood cells, cells in nervous tissue, cells of the immune system, and lung cells, where it is particularly important because oxygen concentrations in those cells are high.[37] Vitamin E

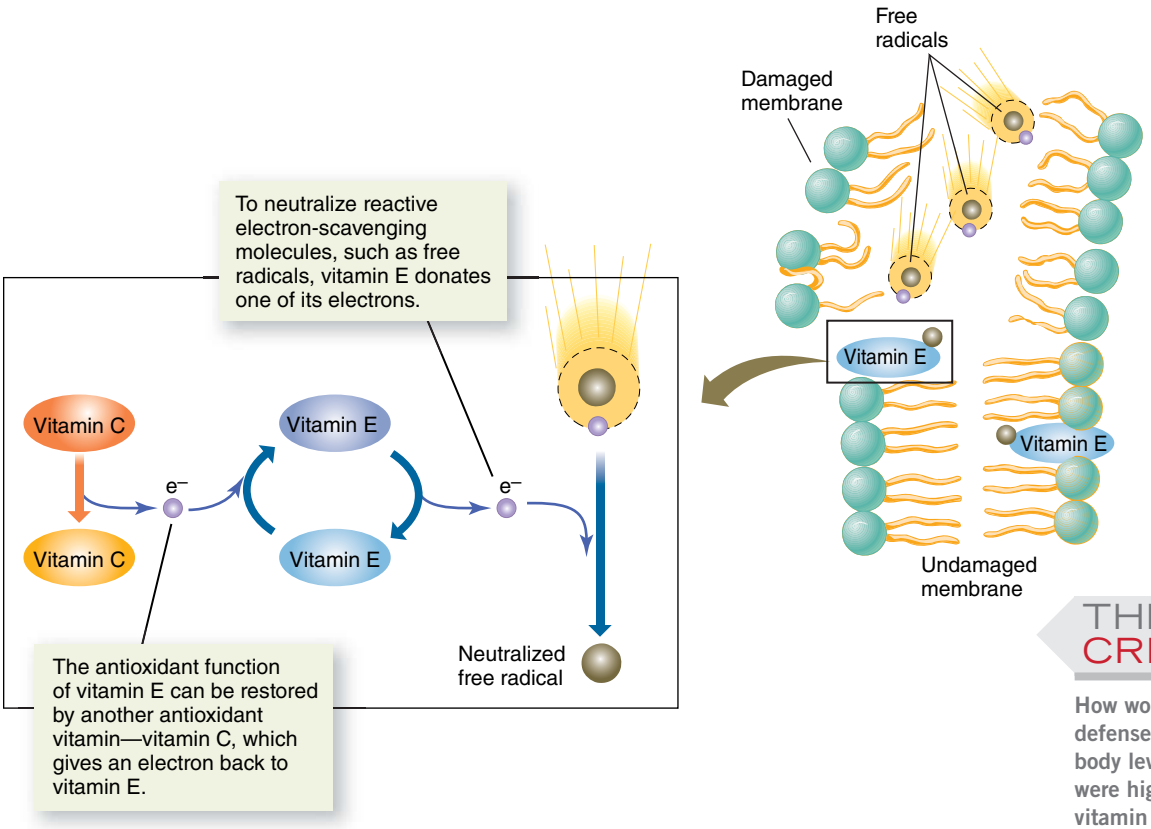


FIGURE 9.16 Antioxidant mechanism of vitamin E
By neutralizing free radicals, vitamin E guards not only cell membranes, as shown here, but also body proteins, DNA, and cholesterol. Vitamin C restores vitamin E to the form that can act as an antioxidant.

THINK CRITICALLY

How would antioxidant defenses be affected if body levels of vitamin E were high, but levels of vitamin C were low?

can also defend cells from damage by heavy metals, such as lead and mercury, and toxins, such as carbon tetrachloride, benzene, a variety of drugs, and some environmental pollutants such as ozone. Vitamin E has also been found to be important for immune function and to inhibit platelet aggregation, which is an early step in blood clot formation.[38] Blood clots are involved in the development of heart attacks and strokes. These vitamin E functions, along with its antioxidant role, are hypothesized to reduce the risk of heart disease and other chronic disorders.

Vitamin E Deficiency

Because vitamin E is needed to protect cell membranes, a deficiency causes those membranes to break down. Red blood cells and nerve cells are particularly susceptible. With a vitamin E deficiency, red blood cell membranes may rupture, causing a type of anemia called **hemolytic anemia**. This is most common in premature infants. All newborn infants have low blood vitamin E levels because there is little transfer of this vitamin from mother to fetus until the last weeks of pregnancy. The levels are lower in premature infants because they are born before much vitamin E has been transferred from the mother. To prevent vitamin E deficiency in premature infants, they can be fed special formulas that contain higher amounts of vitamin E.

hemolytic anemia Anemia that results when red blood cells break open.

Vitamin E deficiency is rare in adults, occurring only in conjunction with other health problems that interfere with vitamin E absorption or transport.[38] In such cases, the vitamin E deficiency is characterized by symptoms associated with nerve degeneration, such as poor muscle coordination, weakness, and impaired vision. For example, vitamin E deficiency can develop rapidly in individuals with cystic fibrosis, an inherited condition that reduces fat absorption, causing serious neurological problems that, if untreated, can become permanent.

Recommended Vitamin E Intake

The recommendation for vitamin E intake is based on the amount needed to maintain plasma concentrations of α-tocopherol that protect red blood cell membranes from rupturing. The RDA for adult men and women is set at 15 mg/day of α-tocopherol.[39]

For infants, an AI for vitamin E has been set based on the amount consumed by infants fed principally with human milk. EARs and RDAs for children and adolescents have been estimated from adult values. The RDA for pregnancy is not increased above nonpregnant levels. To estimate the requirement for lactation, the amount secreted in human milk is added to the requirement for nonlactating women.[39]

Vitamin E Toxicity and Supplements

It is estimated that more than 90% of Americans consume less than the EAR (12 mg) for vitamin E;[40] adults ages 20 and older consume only about 9 mg/day.[17] Despite this, Americans have no obvious ill effects and circulating levels of α-tocopherol are not abnormal,[40] so supplements are not generally recommended to help people meet needs. Supplements are, however, promoted to grow hair; restore, maintain, or increase sexual potency and fertility; alleviate fatigue; maintain immune function; enhance athletic performance; reduce the symptoms of PMS and menopause; slow aging; and treat a host of other medical problems. There is little conclusive evidence that supplemental vitamin E provides any of these benefits.

The antioxidant role of vitamin E suggests that it may help reduce the risk of heart disease, cancer, Alzheimer's disease, macular degeneration, and a variety of other chronic diseases associated with oxidative damage. Particular attention has been paid to its potential benefits in guarding against heart disease.

As an antioxidant, vitamin E helps protect LDL cholesterol from oxidation. In addition to the potential for vitamin E to protect against cardiovascular disease through its antioxidant function, there is evidence that it may also have anti-inflammatory functions and be involved in modulating the immune response, regulating genes that affect cell growth and cell death, and detoxifying harmful substances.[41] Studies examining the relationship between blood levels of vitamin E or vitamin E intake and the incidence of cardiovascular disease have been mixed, and studies investigating the effect of vitamin E supplements on the incidence of cardiovascular disease and other chronic diseases in humans have failed to provide evidence of any benefits.[42,43] The best approach is to get plenty of dietary vitamin E.

Vitamin E is relatively nontoxic. There is no evidence of adverse effects from consuming large amounts from food. The UL is 1000 mg/day from supplemental sources.[39] Vitamin E supplements should not be taken by individuals taking blood-thinning medications because it reduces blood clotting and interferes with the action of vitamin K.

9.6 Vitamin K

LEARNING OBJECTIVES

- Describe how vitamin K is involved in blood clotting.
- Explain why newborns and people taking antibiotics are at risk for vitamin K deficiency.

Vitamin K is one of the few vitamins about which extravagant claims are not made. Like the other fat-soluble vitamins, it was discovered inadvertently by feeding animals a fat-free diet. In this case, researchers in Denmark noted that chicks fed this diet developed a bleeding disorder that was cured by feeding them a fat-soluble extract from green plants. Vitamin K was named for *koagulation*, the Danish word for **coagulation**, or blood clotting.

coagulation The process of blood clotting.

Vitamin K in the Diet

phylloquinone The form of vitamin K found in plants.

Like other fat-soluble vitamins, vitamin K is found in several forms. **Phylloquinone** is the form found in plants and the primary form in the diet. Certain vitamin K compounds, called

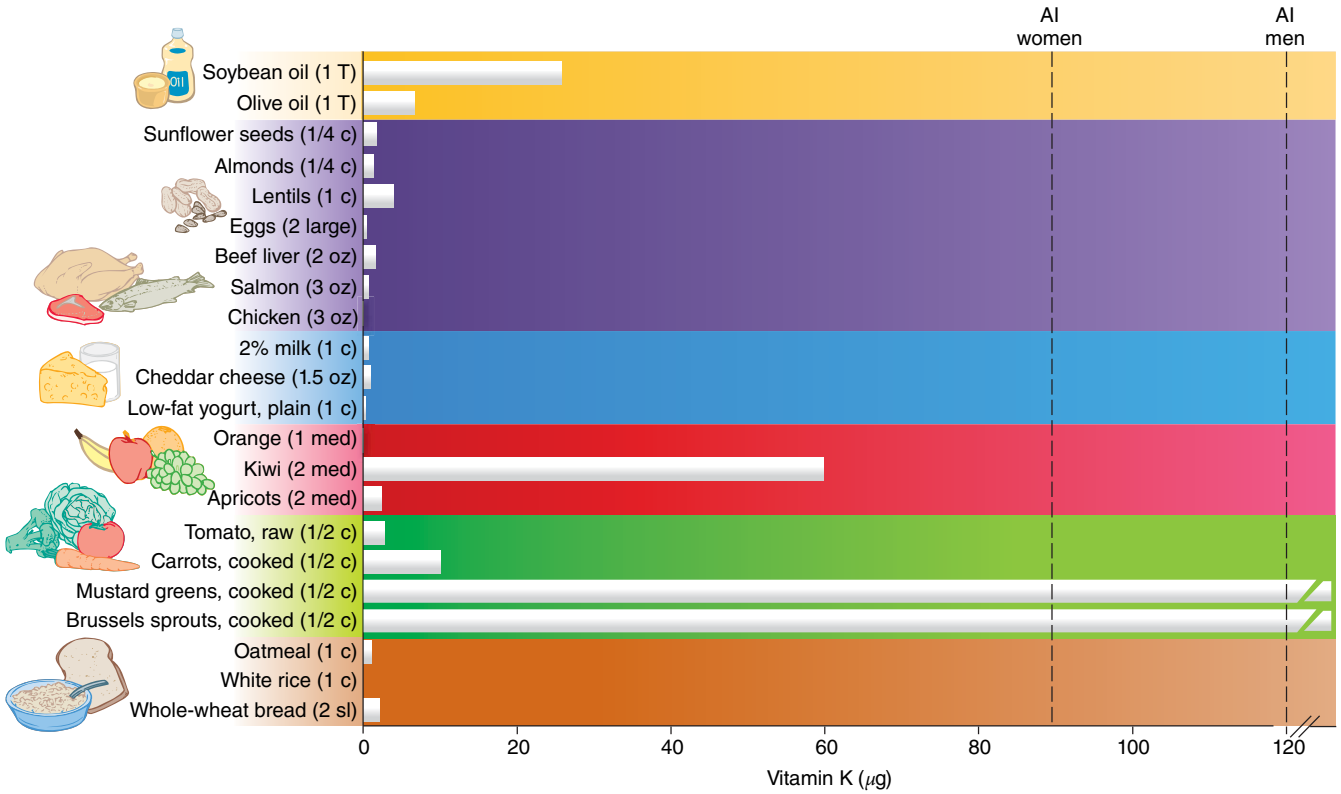


FIGURE 9.17 Vitamin K content of MyPlate food groups
The best sources of vitamin K are leafy green vegetables and some plant oils; the dashed lines represent the AIs for adult women and men.

menaquinones, are found in fish oils and meats and are synthesized by bacteria, including those in the human intestine. Menaquinones are the form found in supplements. Only a small number of foods provide significant amounts of vitamin K; however, typical intakes in the United States meet recommendations.[4] The best dietary sources are liver and leafy green vegetables such as spinach, broccoli, Brussels sprouts, kale, and turnip greens. Some vegetable oils are also good sources (Figure 9.17). Some of the vitamin K produced by bacteria in the human gastrointestinal tract is also absorbed. Vitamin K is destroyed by exposure to light and low- or high-acid conditions.

menaquinones The forms of vitamin K synthesized by bacteria and found in animals.

How Vitamin K Functions in the Body

Vitamin K is a coenzyme needed for the production of **prothrombin** and other specific blood-clotting factors (Figure 9.18). Blood-clotting factors are proteins that circulate in the blood in an inactive form. When activated, they lead to the formation of fibrin, the protein that forms the structure of a blood clot. Injuries, as well as the normal wear and tear of daily living, produce small tears in blood vessels. To prevent blood loss, these tears must be repaired with blood clots. In addition to its role in blood clotting, vitamin K is needed for the synthesis of a number of proteins involved in bone formation and breakdown, inhibition of blood vessel calcification, and regulation of cell growth.[44,45]

prothrombin A blood protein required for blood clotting.

Metabolism

Vitamin K Deficiency

Abnormal blood coagulation is the major symptom of vitamin K deficiency. When vitamin K is deficient, the blood does not clot to seal ruptured blood vessels and blood loss goes unchecked. If the deficiency is severe, it can eventually cause death from blood loss. Because of the roles of vitamin K–dependent proteins that do not function in blood clotting, mild vitamin K deficiency

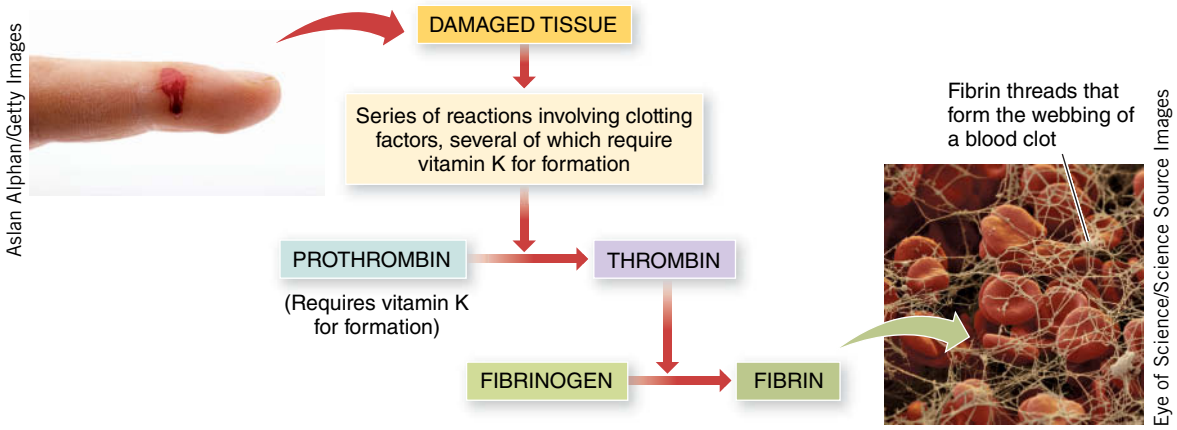


FIGURE 9.18 Role of vitamin K in blood clotting
Blood clotting requires a series of reactions that result in the formation of a fibrous protein called *fibrin*. Fibrin fibers form a net that traps platelets and blood cells and forms the structure of a blood clot. Several clotting factors, including prothrombin, require vitamin K for synthesis. If vitamin K is deficient, they are not made correctly, and the blood will not clot.

is believed to be responsible for a reduction in bone mineral density with an increased risk of fractures due to osteoporosis, an increase in vascular calcification that contributes to the risk of atherosclerosis, and an increase in cancer risk.[44]

A frank deficiency is very rare in the healthy adult population because vitamin K is synthesized by bacteria in the large intestine. Deficiency can be precipitated by a poor diet; Crohn's disease, which damages the colon, limiting absorption; and long-term antibiotic use, which kills the bacteria in the gastrointestinal tract that synthesize the vitamin.

LIFE CYCLE

Vitamin K deficiency is most common in newborns. There is little transfer of this vitamin from mother to fetus, and because the infant gut is free of bacteria, no vitamin K is made there. Further, breast milk is low in vitamin K. Therefore, to prevent uncontrolled bleeding, infants are typically given a vitamin K injection within six hours of birth.

Injections of vitamin K are typically administered before surgery to aid in blood clotting. Because inappropriate blood clotting causes strokes and heart attacks, drugs that block vitamin K activity have been used to reduce blood-clot formation in patients with cardiovascular disease (see **Science Applied: Saving Cows, Killing Rats, and Surviving Heart Attacks**).

Recommended Vitamin K Intake

Unlike other fat-soluble vitamins, the body uses vitamin K rapidly, so a constant supply is necessary. The vitamin K produced by bacteria in the gastrointestinal tract contributes to needs, but this is not well absorbed and alone is not enough to meet requirements. An AI for dietary vitamin K has been set at 120 μg/day for men and 90 μg/day for women. The AI is not increased for pregnancy or lactation. An AI for infants was set based on the amount typically consumed in breast milk.

There is concern that typical intakes in North America provide enough vitamin K for normal blood coagulation, but not enough for adequate synthesis of other vitamin K–dependent proteins. Evidence is accumulating that the current recommendations may not be high enough to provide for all the functions of vitamin K.[46]

Vitamin K Toxicity and Supplements

A UL has not been established for vitamin K because there are no well-documented side effects, even with intakes up to 370 μg/day from food and supplements. Because vitamin K functions in blood clotting, high doses can interfere with anticoagulant drugs. Therefore, individuals prescribed these medications should consult with their physicians before taking supplements containing vitamin K. A summary of the sources, recommended intakes, functions, deficiencies, and toxicities of vitamin K and the other fat-soluble vitamins is provided in Table 9.2.

SCIENCE APPLIED

Saving Cows, Killing Rats, and Surviving Heart Attacks

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

In the 1930s, hemorrhagic sweet clover disease was killing cows across the prairies of the midwestern United States and Canada. It occurred in cattle that were fed moldy, spoiled sweet clover hay. These animals died because their blood did not clot. Even a minor scratch from a barbed wire fence could be fatal; once bleeding began, it did not stop.

THE SCIENCE

On a snowy night in 1933, a disgruntled farmer delivered a bale of moldy clover hay, a pail of unclotted blood, and a dead cow to the laboratory of Dr. Karl Link at the University of Wisconsin. Link, the university's first professor of biochemistry, was already making a name for himself in the scientific community when he was presented with this challenge. What was in the clover that killed the man's cows? What could he do to stop the bleeding disease that was killing them? Link had just begun to research hemorrhagic sweet clover disease, but at the time the only advice he could offer the farmer was to find alternative feed and try blood transfusions to save his remaining animals. Link and his colleagues began a line of inquiry that ultimately led to the development of an anti–blood-clotting factor that today saves the lives of hundreds of thousands of people.

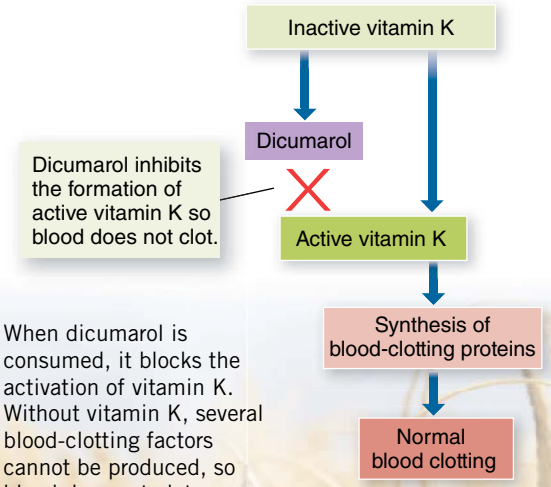
Six years after the farmer's challenge, Link and colleagues had isolated the anticoagulant *dicumarol* from moldy clover. Dicumarol is a derivative of coumarin, which gives clover its sweet scent; mold converts coumarin to dicumarol. Cows fed moldy clover consume dicumarol, which interferes with vitamin K activity and consequently prevents normal blood clotting (see figure).

THE APPLICATION

The discovery of dicumarol enhanced our understanding of the blood-clotting mechanism and led to the development of anticoagulant drugs. These drugs help eliminate blood clots and prevent their formation. In carefully regulated doses, they are used to prevent and treat heart attacks, which occur when blood clots block blood flow to the heart muscle. Dicumarol, first synthesized in 1940, was the first anticoagulant that could be administered orally to humans. Further work with dicumarol led Link to propose the use of a more potent derivative, called *warfarin*, as rat poison. The name *warfarin* comes from the initials of the Wisconsin Alumni Research Foundation (WARF), which patented the drug, and from coumarin, the compound from which it is derived. When rats consume the odorless, colorless warfarin, their blood fails to clot, and they bleed to death. Warfarin was used as a rodenticide for nearly a decade before it was introduced into clinical medicine in 1954. Sodium warfarin, also known by the brand name Coumadin, soon became the most widely prescribed anticoagulant drug in the nation. It was used to treat President Dwight D. Eisenhower when he suffered a heart attack in 1955.

Sodium warfarin and dicumarol have been administered to millions of patients to prevent heart attacks and strokes caused by blood clots. Thus, a substance that killed hundreds of cattle across the Great Plains during the Great Depression and today efficiently kills rodents invading our homes also saves a multitude of human lives.

THINK CRITICALLY: Why should patients taking warfarin avoid supplements that contain vitamin K?



When dicumarol is consumed, it blocks the activation of vitamin K. Without vitamin K, several blood-clotting factors cannot be produced, so blood does not clot.

TABLE 9.2 A Summary of the Fat-Soluble Vitamins (All Values Are RDAs Unless Otherwise Noted)

Vitamin	Sources	Recommended intake for adults	Major functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
Vitamin A (retinol, retinal, retinoic acid, vitamin A acetate, vitamin A palmitate, retinyl palmitate, pro-vitamin A, carotene, β-carotene, carotenoids)	Retinol: liver, fish, fortified milk and margarine, butter, eggs; carotenoids: carrots, leafy greens, sweet potatoes, broccoli, apricots, cantaloupe	700–900 μg/day	Vision, health of cornea and other epithelial tissue, cell differentiation, reproduction, immune function	Xerophthalmia: night blindness, dry cornea, eye infections; poor growth, dry skin, impaired immune function	People living in poverty (particularly children and pregnant women), people who consume very low-fat or low-protein diets	Headache, vomiting, hair loss, liver damage, skin changes, bone pain, fractures, birth defects	3000 μg/day of preformed vitamin A
Vitamin D (calciferol, cholecalciferol, calcitriol, ergocalciferol, dihydroxy vitamin D)	Egg yolk, liver, fish oils, tuna, salmon, fortified milk, synthesis from sunlight	600–800 IU/day (15–20 μg/day)	Absorption of calcium and phosphorus, maintenance of bone	Rickets in children: abnormal growth, misshapen bones, bowed legs, soft bones; osteomalacia in adults: weak bones and bone and muscle pain	Some breast-fed infants; children and older adults (especially those with dark skin and little exposure to sunlight); people with kidney disease	Calcium deposits in soft tissues, growth retardation, kidney damage	4000 IU/day (100 μg/day)
Vitamin E (tocopherol, α-tocopherol)	Vegetable oils, leafy greens, seeds, nuts, peanuts	15 mg/day	Antioxidant, protects cell membranes	Broken red blood cells, nerve damage	People with poor fat absorption, premature infants	Inhibition of vitamin K activity	1000 mg/day from supplemental sources
Vitamin K (phylloquinone, menaquinone)	Vegetable oils, leafy greens, synthesis by intestinal bacteria	90–120 μg/day[a]	Synthesis of blood-clotting proteins and proteins in bone	Hemorrhage, reduced bone density	Newborns (especially premature), people on long-term antibiotics	Anemia, brain damage, liver damage	ND

[a]Adequate Intake (AI).
Note: UL, Tolerable Upper Intake Level; ND, not determined due to insufficient data.

9.7 Vitamin/Mineral Supplements

LEARNING OBJECTIVES

- List three population groups for whom supplements are recommended, and explain which supplements are recommended and why.
- Discuss five factors you should consider before purchasing and taking a dietary supplement.

Currently, 68% of all adult Americans consider themselves supplement users.[47] People take dietary supplements to energize themselves, to protect themselves from disease, to cure their illnesses, to enhance what they get in food, and simply to ensure against deficiencies. Whether

these products are necessary to meet needs, harmful, or just a waste of money depends on who is taking them and in what amounts.

Who Needs Vitamin/Mineral Supplements?

Eating a variety of foods is the best way to meet nutrient needs, and most healthy adults who consume a reasonably good diet do not need supplements.[48] A varied diet provides phytochemicals and other substances that are not nutrients but that have health-promoting properties. And epidemiological studies show that people who eat more fruits and vegetables have a lower incidence of a host of chronic diseases. These benefits are not duplicated by taking supplements of nutrients found in these foods. In fact, an argument against the use of supplements is that supplement use gives people a false sense of security, causing them to pay less attention to the nutrient content of the foods they choose.

Although supplements do not provide all the benefits of a diet containing a wide variety of foods, there is little evidence that a multivitamin/mineral supplement will cause harm.[48] For some people, supplements may be the only way to meet certain nutrient needs because they have low intakes, increased needs, or excess losses. Groups for whom vitamin and mineral supplements are typically recommended and the type of supplement are given in Table 9.3.

Choose Supplements with Care

Despite the benefits of supplements to some individuals, they can also carry risks. Concentrated doses of vitamins and minerals can result in toxicity, and supplements of other substances, such as herbs, may have side effects that outweigh any benefits they may provide (see Focus on Dietary Supplements). Certain people should not take certain supplements. For example, smokers should not take β-carotene supplements, and people who are unable to regulate iron absorption need to avoid iron supplements. People who tend to develop kidney stones should avoid vitamin C supplements. People taking medications should also be cautious because some interact with supplements. For example, taking supplements of vitamin E or vitamin K can alter the effectiveness of anticoagulant medications. Individuals who routinely take medications should discuss nutrient–drug interactions and the need for specific vitamin and mineral supplementation with their doctor or pharmacist.

TABLE 9.3 Groups for Whom Dietary Supplements Are Recommended[49]

Group	Recommendation
Dieters	People who consume fewer than 1200 kcal should take a multivitamin/multimineral supplement.
Vegans and those who eliminate all dairy foods	To obtain adequate vitamin B_{12}, people who do not eat animal products need to take supplements or consume vitamin B_{12}–fortified foods. Because dairy products are an important source of calcium and vitamin D, those who do not consume dairy products may benefit from supplemental sources of calcium and vitamin D.
Infants and children	Supplemental fluoride, vitamin D, and iron are recommended under certain circumstances.
Young women and pregnant women	Women of childbearing age should consume 400 μg of folic acid daily from either fortified foods or supplements. Supplements of iron and folic acid are recommended for pregnant women, and multivitamin/multimineral supplements are usually prescribed during pregnancy.
Older adults	Because of the high incidence of atrophic gastritis in adults over age 50, vitamin B_{12} supplements or fortified foods are recommended. It may also be difficult for older adults to meet the RDAs for vitamin D and calcium, so supplemental sources of these nutrients are often recommended.
Individuals with dark skin pigmentation	People with dark skin may be unable to synthesize or consume enough vitamin D to meet their needs for this vitamin and may therefore require supplements.
Individuals with restricted diets	Individuals with health conditions that affect what foods they eat or how nutrients are used may require vitamin and mineral supplements.
People taking medications	People taking medications that interfere with the body's use of certain nutrients may require supplements of these nutrients.
Cigarette smokers and alcohol users	People who smoke heavily require more vitamin C and possibly vitamin E than do nonsmokers.[41,50] Alcohol consumption inhibits the absorption of B vitamins and may interfere with B vitamin metabolism.

OFF THE LABEL

Read the Label Before You Supplement

© iStockphoto

You can purchase almost any nutrient as an individual supplement or you can choose from a surfeit of combinations of nutrients, herbs, and other components. The labels entice you with descriptions like "all natural," "mega," "advanced formula," "high potency," and "ultra." If you need a supplement or choose to take one, how can you decide which is best?

If you want to take a dietary supplement, some common sense and the information on the label will help you choose. Supplement labels are required to carry a standardized Supplement Facts panel (see figure and Chapter 2) that can be used to determine if a supplement includes the nutrients you want in appropriate amounts. For example, if you are looking for a vitamin/mineral supplement, the Supplement Facts panel will indicate if it provides minerals as well as vitamins. If you want to increase your calcium intake, check to see if it provides the amount of calcium you want. If you have low iron stores, check to see if it provides iron. If you are over age 50 or eat a vegan diet, check to see if it provides enough vitamin B_{12} to meet your needs. Special supplement formulas for men, seniors, and women are available but may not necessarily provide what you need even if you are in the group they target. These formulations are not defined or regulated, so it is up to the company to decide what they contain.

Be sure to look at the serving size. If the serving is one tablet, the Supplement Facts will be shown for one tablet—if you take two, you'll have to double the numbers. The amounts of nutrients contained in a dose vary depending on the supplement. Some contain less than or equal to 100% of the Daily Value, while others supply two, three, or ten times the Daily Value. High doses of individual nutrients or combinations of several different nutrients or other substances can lead to nutrient imbalances or toxicities.

To assess the safety of the amounts of nutrients in a supplement dose, compare it to the ULs (see inside cover). If the supplement contains amounts of nutrients in excess of the UL, symptoms of toxicity are more likely to occur. Remember to consider all the supplements you are taking when assessing your total intake and potential toxicity. Although the ULs are a good guide, they are not available for all the substances found in supplements. For example, there are no ULs or Daily Values for herbs, carotenoids, and other phytochemicals, so it is difficult to assess whether the amount in a supplement is too low to be of benefit or high enough to be harmful.

THINK CRITICALLY: If you took two tablets of the vitamin/mineral supplement shown here, would it pose a risk for nutrient toxicity?

Supplement Facts

Serving Size 1 Tablet

Each Tablet Contains	% DV
Vitamin A 5000 IU (20% as Beta Carotene)	100%
Vitamin C 60 mg	100%
Vitamin D 400 IU	100%
Vitamin E 30 IU	100%
Vitamin K 25 mcg	31%
Thiamin 1.5 mg	100%
Riboflavin 1.7 mg	100%
Niacin 20 mg	100%
Vitamin B6 2 mg	100%
Folic Acid 400 mcg	100%
Vitamin B12 6 mcg	100%
Biotin 30 mcg	10%
Pantothenic Acid 10 mg	100%
Calcium 162 mg	16%
Iron 18 mg	100%
Phosphorus 109 mg	11%
Iodine 150 mcg	100%
Magnesium 100 mg	25%
Zinc 15 mg	100%
Selenium 20 mcg	29%
Copper 2 mg	100%
Manganese 2 mg	100%

Each Tablet Contains	% DV
Chromium 120 mcg	100%
Molybdenum 75 mcg	100%
Chloride 72 mg	2%
Potassium 80 mg	2%
Boron 150 mcg	*
Nickel 5 mcg	*
Silicon 2 mg	*
Tin 10 mcg	*
Vanadium 10 mcg	*
Lutein 250 mcg	*

*Daily Value (%DV) not established.

SUGGESTED USE:
Adults - One tablet daily

WARNING: Accidental overdose of iron-containing products is a leading cause of fatal poisoning in children under 6. Keep this product out of reach of children. In case of accidental overdose, call a doctor or poison control center immediately.

Keep bottle tightly closed.
Store at room temperature.

George Semple

Thousands of dietary supplements are on the market. They contain a multitude of nutrients and other ingredients, some of which may pose a risk of toxicity.

Supplements can be part of an effective strategy to promote good health, but they should never be considered a substitute for other good health habits, and they should never be used instead of medical therapy to treat a health problem. If you choose to use dietary supplements, a safe choice is a multivitamin/mineral supplement that does not exceed 100% of the Daily Values (see **Off the Label: Read the Label Before You Supplement**). Here are a number of suggestions that will help you when choosing or using dietary supplements:

- **Consider why you want it**. If you are taking it to ensure good health, does it provide both vitamins and minerals? If you want to supplement specific nutrients, are they contained in the product?
- **Compare product costs**. Just as more isn't always better, more expensive is not always better either.
- **Read the label**. Does the supplement contain potentially toxic levels of any nutrient? Are you taking the amount recommended on the label? For any nutrients that exceed 100% of the Daily Value, check to see if they exceed the UL (see UL table in the back cover of the book). Does the supplement contain any nonvitamin/nonmineral ingredients? If so, have any of them been shown to be toxic to someone like you?
- **Check the expiration date**. Some nutrients degrade over time, so expired products will have a lower nutrient content than is shown on the label. This is particularly true if the product has not been stored properly.
- **Consider your medical history**. Do you have a medical condition that recommends against certain nutrients or other ingredients? Are you taking prescription medication that an ingredient in the supplement may interact with? Check with a physician, dietitian, or pharmacist to help identify these interactions.
- **Approach herbal supplements with caution**. If you are pregnant, ill, or taking medications, consult your physician before taking herbs. Do not give them to children. Do not take combinations of herbs. Do not use herbs for long periods. Stop taking any product that causes side effects.
- **Report harmful effects**. If you suffer a harmful effect or an illness that you think is related to the use of a supplement, seek medical attention and go to the FDA reporting website for information about how to proceed.

OUTCOME

Ayana is now a happy, healthy 2-year-old. You would never know that a year ago she had been diagnosed with a vitamin D deficiency disease. She developed rickets because breast milk is low in vitamin D and she was not exposed to enough sunlight to synthesize adequate amounts of the vitamin to meet her needs. Without adequate vitamin D, she was unable to absorb sufficient calcium to support bone growth and health. After diagnosing Ayana with rickets, her pediatrician prescribed oral supplements of both vitamin D and calcium and recommended that Ayana consume a calcium-rich diet. After only a week of treatment, Ayana's laboratory values had improved, and X-rays showed that her bones were healing. After a few months, the bony protrusions on her ribs had disappeared, the slight bowing in her legs was corrected, and new teeth began to emerge. If Ayana had not been treated when she was young and still growing, her skeletal deformities would have been permanent.

Ayana's mother is now pregnant with her second child. She now understands that having dark skin and living in an area where there is little sunshine during the winter months means that it is important to get enough vitamin D in her diet. She cannot drink milk, an important dietary source of calcium and vitamin D, but she does drink soymilk that is fortified with both these nutrients. **She plans to breast-feed the new baby, but now knows that the baby will also need vitamin D supplements.**

SUMMARY

9.1 Fat-Soluble Vitamins in Our Diet

- Vitamins A, D, E, and K are soluble in fat, which affects how they are absorbed, transported, stored, and excreted. Deficiencies of vitamins A and D are common in the developing world. In the United States, the risk of deficiencies of fat-soluble vitamins is increasing due to low intakes of fruits and vegetables and limited sun exposure.

9.2 Vitamin A Sources and Functions

- Vitamin A is found both preformed as retinoids and in precursor forms called carotenoids. The major food sources of preformed vitamin A include liver, eggs, fish, and fortified dairy products. Carotenoids are found in plant foods such as yellow-, orange-, and red-colored fruits and vegetables and leafy green vegetables. Some carotenoids are precursors of vitamin A. The most potent is β-carotene.
- Preformed vitamin A and carotenoids are bound to proteins in food. To be absorbed they must be released and incorporated into micelles. Fat malabsorption and very-low-fat diets reduce vitamin A absorption.
- In the body, the retinoids, which include retinol, retinal, and retinoic acid, are needed for vision and for the growth and differentiation of cells. Retinol is transported in the blood and can be converted into retinal or retinoic acid. Retinal binds to opsin in the eye to form rhodopsin. After light strikes rhodopsin to begin the visual cycle, a nerve impulse is sent to the brain so the light is perceived. Retinoic acid affects cell differentiation by altering gene expression. It is needed for healthy epithelial tissue and normal reproduction and immune function. β-Carotene functions as an antioxidant, a role that is independent of its conversion to vitamin A.

9.3 Meeting Vitamin A Needs

- Vitamin A deficiency is a world health problem that increases the frequency of infectious disease and causes blindness and death in hundreds of thousands of children. Mild vitamin A deficiency causes night blindness. More severe deficiency interferes with cell differentiation. This impairs immune function and growth and causes the epithelial surface of the eye to become hard and dry, leading to infection and blindness.
- The need for vitamin A can be met with preformed or provitamin A. Preformed vitamin A can be toxic at doses as low as 10 times the RDA and can increase the risk of bone fractures and birth defects. Carotenoids are not toxic, but a high intake can give the skin an orange appearance.

9.4 Vitamin D

Go to WileyPLUS to view a video clip on Vitamin D.

- Vitamin D can be made in the skin by exposure to sunlight, so dietary needs vary depending on the amount synthesized. Vitamin D is found in fatty fish, cod liver oil, and fortified milk.
- Dietary vitamin D as well as vitamin D synthesized in the skin must be modified by the liver and then the kidney to form active vitamin D. Active vitamin D promotes calcium and phosphorus absorption from the intestines and acts with parathyroid hormone to cause the release of calcium from bone and calcium retention by the kidney. These roles are essential for maintaining proper levels of calcium and phosphorus in the body.
- Vitamin D deficiency in children results in a condition called rickets; in adults, vitamin D deficiency causes osteomalacia. The risk of vitamin D deficiency is increased by factors such as living at latitudes greater than 40° north or south, working and playing indoors, wearing concealing clothing, the presence of pollution and tall buildings, having dark skin, and using sunscreen that reduce the amount of sunlight that penetrates the skin.
- The RDA for vitamin D assumes limited sun exposure because the amount that is synthesized in the skin is extremely variable. Vitamin D supplements are recommended for a number of groups including breast-fed babies, people who do not drink milk, older adults, and individuals with dark skin pigmentation or limited sun exposure. Too much vitamin D is toxic, but synthesis of vitamin D from exposure to sunlight does not produce toxic amounts.

9.5 Vitamin E

- Vitamin E is found in nuts, plant oils, leafy green vegetables, and fortified cereals.
- Vitamin E functions primarily as a fat-soluble antioxidant. It is necessary for reproduction and protects cell membranes from oxidative damage.
- Vitamin E deficiency can cause hemolytic anemia and neurological problems.
- Many people take vitamin E supplements. There is little risk of toxicity, but there is also little documented evidence of any benefit from supplements.

9.6 Vitamin K

- Vitamin K is found in plants and is synthesized by bacteria in the gastrointestinal tract.
- Vitamin K is a coenzyme essential for the formation of blood-clotting factors as well as proteins needed for normal bone mineralization and to prevent calcification of blood vessels.
- Deficiency causes bleeding, low-bone density, and an increased risk of atherosclerosis. Because vitamin K deficiency is a problem in newborns, they are routinely given vitamin K injections at birth.

9.7 Vitamin/Mineral Supplements

- Some groups require supplements to meet the need for certain nutrients, because they have low intakes, increased needs, or excess losses. This includes dieters, vegans, infants and children, pregnant women and women of childbearing age, older adults, individuals with dark skin pigmentation, and people who have restricted diets, are taking medications, or who smoke or use alcohol.
- Appropriate supplement use can promote health, but supplements should never be considered a substitute for other good health habits and they should never be used instead of medical therapy to treat a health problem.

FOCUS ON Phytochemicals

© Valentyn Volkov/iStockphoto

CHAPTER OUTLINE

FOCUS 3.1 **Phytochemicals in Our Food**
- Carotenoids
- Flavonoids
- Indoles, Isothiocyanates, and Alliums
- Phytoestrogens

FOCUS 3.2 **How to Choose a Phytochemical-Rich Diet**
- Eat More Fruits and Vegetables
- Make Half Your Grains Whole
- Choose Plant Proteins
- Added versus Naturally Occurring Phytochemicals

functional foods Foods that provide a potential benefit to health beyond that attributed to the nutrients they contain.

Food offers an unlimited array of tastes, textures, colors, and aromas. With this gastronomic variety and delight come a myriad of nutrient combinations. In addition, food contains substances that have not been identified as nutrients but may promote health and reduce disease risk. Foods have been used in folk medicine for centuries. Today, researchers continue to discover beneficial effects of various food components and explore the relationships among the consumption of specific foods, typical dietary patterns, and health. Foods that provide health benefits beyond basic nutrition are called **functional foods**.[1] Table F3.1 provides examples of functional foods and their potential benefits. **Health-promoting substances in plant foods are called *phytochemicals*, whereas those found in animal foods are called *zoochemicals*.**

TABLE F3.1 Benefits of Functional Foods

Food	Potential health benefit
Blueberries	May reduce the risk of heart disease and cancer.[2]
Breakfast cereal with added flaxseed	Helps reduce blood pressure, blood cholesterol levels, and the overall risk of heart disease.[3,4]
Chocolate	May help reduce risk factors for heart disease.[5]
Garlic	Helps reduce blood cholesterol levels and the overall risk of heart disease.[6]
Kale	May reduce the risk of age-related blindness (macular degeneration).[7]
Margarine with added plant sterols	Reduces blood cholesterol levels.[8]
Nuts	May reduce the risk of heart disease and cancer.[9]
Oatmeal	Helps reduce blood cholesterol.[10]
Orange juice with added calcium	Helps prevent osteoporosis.[11]
Salmon	Reduces the risk of heart disease.[12]
Tea, green and black	May reduce the risk of certain types of cancer.[13]
Whole-grain products	Helps reduce the risk of cancer, heart disease, obesity, and diabetes.[14]

F3.1 Phytochemicals in Our Food

LEARNING OBJECTIVES

- Distinguish phytochemicals from essential nutrients.
- Discuss how the color of fruits and vegetables is related to their phytochemical content.
- Give some examples of the health benefits of phytochemicals.

Phytochemicals include the hundreds, perhaps thousands, of biologically active nonnutritive chemicals found in plants. In the plants themselves, phytochemicals provide biological functions. For example, compounds in onions and garlic are natural pesticides that protect plants from insects. Gardeners often plant these near more vulnerable plant varieties to protect them from insect infestation. Most plant chemicals have no effect on human health, but some promote health, and a few can be toxic. For example, the phytochemicals in soy and tea have been shown to inhibit tumor growth.[13,15] On the other hand, chemicals in rhubarb leaves can cause symptoms ranging from burning in the mouth and throat, abdominal pain, nausea, vomiting, and diarrhea to convulsions, coma, and death from cardiovascular collapse (Figure F3.1). Despite the variety of effects these chemicals can have, the term *phytochemical* is generally used to refer to those substances found in plants that have health-promoting properties. Phytochemicals are responsible for the health-promoting properties afforded by a variety of natural functional foods.

antioxidant A substance that decreases the adverse effects of reactive molecules on normal physiological function.

The phytochemicals in our diet protect our health in a variety of ways. Some, such as carotenoids, are **antioxidants** (see Chapters 8 and 9). Others provide benefits because they mimic the structure or function of natural substances in the body. Phytoestrogens, such as those in soy for instance, have structures similar to the hormone estrogen and affect us by blocking or mimicking estrogen action. Phytosterols resemble cholesterol in structure and thus compete with cholesterol for absorption from the gastrointestinal tract. Their presence reduces cholesterol absorption and helps lower blood cholesterol—a major risk factor for cardiovascular disease. Some phytochemicals stimulate the body's natural

Image Source/Getty Images, Inc.

FIGURE F3.1 Rhubarb leaves are toxic
Not all of the chemicals in plants benefit our health. The leaves of the rhubarb plant are poisonous. The stems have lower levels of the toxin and are safe to eat.

carcinogen A substance that causes cancer.

defenses. For example, indoles and isothiocyanates found in broccoli stimulate the activity of enzymes that help deactivate **carcinogens**. Other phytochemicals are health promoting because they can alter the way in which cells communicate, affect DNA repair mechanisms, or influence other cell processes that may affect cancer development.[16] The phytochemicals described in this focus are just a few of the ones that have been identified in our food. Many others have been studied and still more have yet to be isolated.

Carotenoids

Carrots, sweet potatoes, acorn squash, apricots, and mangos get their yellow-orange color from the carotenoids they contain. These and other yellow, orange, and red fruits and vegetables as well as leafy greens, in which the color of the carotenoids is masked by the green color of chlorophyll, are the major sources of dietary carotenoids. People who eat more of these have higher blood carotenoid levels. A high intake of carotenoid-containing fruits and vegetables has been associated with a reduced risk of certain cancers, cardiovascular disease, and age-related eye diseases.[17]

Carotenoids are phytochemicals that have antioxidant properties; some also have vitamin A activity (Table F3.2).[17] The most prevalent carotenoids in the North American diet include β-carotene, α-carotene, β-cryptoxanthin, lycopene, lutein, and zeaxanthin. β-Carotene is the best known and provides the most vitamin A activity, but it may be a less effective antioxidant than others. Lycopene, the carotenoid that gives tomatoes their red color, does not provide vitamin A

TABLE F3.2 Phytochemicals in Foods

Phytochemical name or class	Food sources	Biological activities and possible effects
Carotenoids: α-carotene, β-carotene, β-cryptoxanthin, lutein, zeaxanthin, lycopene	Apricots, carrots, cantaloupe, tomatoes, peppers, sweet potatoes, squash, broccoli, spinach, and other leafy greens	Some are converted to vitamin A, provide antioxidant protection, some decrease the risk of macular degeneration.
Flavonoids: flavonols (quercetin, kaempferol, myricetin), flavones (apigenin), flavanols (catechins), anthocyanins, anthocyanidins (cyanidin, delphinidin)	Berries, citrus fruits, onions, purple grapes, green tea, red wine, and chocolate	Make capillary blood vessels stronger, block carcinogens and slow the growth of cancer cells.
Phytoestrogens including lignins and isoflavones such as genistein, biochanin A, and daidzein	Tofu, soymilk, soybeans, flaxseed, and rye bread	Mimic effect of estrogen, reduce menopause symptoms, slow the growth of cancer cells, reduce blood cholesterol, may reduce risk of osteoporosis.
Phytosterols: β-sitosterol, stigmasterol, and campesterol	Nuts, seeds, legumes, and fortified margarine	Decrease cholesterol absorption, reduce the risk of colon cancer by slowing growth of colon cells.
Capsaicin	Hot peppers	Modulates blood clotting.
Glucosinolates, isothiocyanates, indoles	Broccoli, Brussels sprouts, and cabbage	Increase the activity of enzymes that deactivate carcinogens, alter estrogen metabolism, affect the regulation of gene expression.
Sulfides and allium compounds	Onions, garlic, leeks, and chives	Deactivate carcinogens, kill bacteria, protect against heart disease.
Inositol	Sesame seeds and soybeans	Protects against free radicals, protects against cancer.
Saponins	Beans and herbs	Decrease cholesterol absorption, decrease cancer risk, antioxidants.
Ellagic acid	Nuts, grapes, and strawberries	Anticancer properties, prevents the formation of carcinogens in the stomach.
Tannins, catechins	Tea and red wine	Antioxidants, cancer protection.
Curcumin	Turmeric and mustard	Reduces carcinogen formation, antioxidant, anti-inflammatory.
Sulforaphane	Broccoli and other cruciferous vegetables	Detoxifies carcinogens, shown to protect animals from breast cancer.
Limonene	Citrus fruit peels	Inhibits cancer cell growth.

©Datacraft/Age Fotostock America, Inc.

FIGURE F3.2 Lycopene in tomatoes
The red color of tomatoes is due to the carotenoid lycopene, a potent antioxidant. Processing of tomatoes into tomato paste and sauce increases lycopene concentration and bioavailability.

activity, but it is a more potent antioxidant than other dietary carotenoids (Figure F3.2).[18] The carotenoids lutein and zeaxanthin are antioxidants that accumulate in the macula, which is the central portion of the retina of the eye. High intakes of these are associated with reduced risk of **macular degeneration**, the leading cause of blindness in older adults (see Chapter 16).[19]

macular degeneration An incurable eye disorder that is caused by deterioration of the retina of the eye. It is the leading cause of blindness in adults over the age of 55 years.

Flavonoids

Like carotenoids, flavonoids are plant pigments that add color to your plate. They are found in fruits, vegetables, wine, grape juice, chocolate, and tea. One of the most abundant types of flavonoids is the anthocyanins, which give the blue and red colors to blueberries, raspberries, and red cabbage. Other types of flavonoids give the pale yellow color to potatoes, onions, and orange rinds. These compounds are strong antioxidants that protect against cancer and cardiovascular disease.[20] Citrus fruits contain about 60 flavonoids that inhibit blood clotting and have antioxidant, anti-inflammatory, and anticancer properties.

Indoles, Isothiocyanates, and Alliums

Cruciferous vegetables such as broccoli, cauliflower, Brussels sprouts, cabbage, and greens such as mustard and collards are particularly good sources of sulfur-containing phytochemicals (Figure F3.3). These stimulate the activity of enzymes that detoxify carcinogens. Sulforaphane, a phytochemical in broccoli, is particularly effective at boosting the activity of these enzyme systems and has been shown to protect animals from breast cancer.[21] Crucifers also contain a class of phytochemicals called indoles. Indoles protect against cancer in a number of ways, but the most important is by inactivating the hormone estrogen. Exposure to estrogen is believed to increase the risk of cancer; therefore, because indoles reduce estrogen exposure, they protect against hormone-dependent cancers such as breast, cervical, and prostate cancer.[22]

cruciferous A group of vegetables (also called crucifers) named for the cross shape of their four-petal flowers. They include broccoli, Brussels sprouts, cabbage, cauliflower, kale, kohlrabi, mustard greens, rutabagas, and turnips. Their consumption is linked with lower rates of cancer.

Sulfur compounds called allium compounds are found in plants belonging to the species *Allium* such as garlic, onions, leeks, chives, and shallots (Figure F3.4). These phytochemicals boost the activity of cancer-destroying enzyme systems, protect against oxidative damage, and defend against heart disease by lowering blood cholesterol, blood pressure, and platelet activity.[23] In addition, these compounds prevent bacteria in the gut from converting nitrates into nitrites, which can form carcinogens.

iStockphoto

FIGURE F3.3 Cruciferous vegetables
Cruciferous vegetables, such as cabbage and cauliflower, are excellent sources of phytochemicals that may protect against cancer.

Ulrich Kerth/StockFood/Getty Images, Inc.

FIGURE F3.4 Allium vegetables
Garlic and onions provide sulfur-containing phytochemicals that may help protect against cancer and heart disease.

Phytoestrogens

Human hormones help regulate body processes and maintain homeostasis. Plants have hormones too. When ingested, they can affect human health. Phytoestrogens are plant hormones that are believed to interrupt cancer development and affect health by interfering with the action of the human hormone estrogen. Phytoestrogens include isoflavones and lignans. Soy products are particularly rich in isoflavones, and flaxseed and sesame oil are the best sources of lignans.

Phytoestrogens are modified by the intestinal microbiota to form compounds that are structurally similar to estrogen. In some situations they are believed to mimic estrogen and in others to block estrogen function by tying up estrogen receptors on cells. For example, lignin metabolites have been shown to inhibit the growth of estrogen-stimulated breast cancer cells.[24] There is evidence that consuming isoflavones reduces the symptoms of menopause (including hot flashes), reduces bone loss, and affects the risk and progression of breast cancer. A review of studies on the effects of isoflavones on menopause symptoms suggests that the specific isoflavone genistein may reduce hot flashes.[25] Clinical trials support a role of isoflavones in the prevention of bone loss, but results are inconsistent.[26] Isoflavones have been found to promote the growth of breast tumors in animals, and therefore women who have breast cancer are typically advised to avoid soy, which is high in isoflavones.[27] In women without breast cancer, isoflavones from soy appear to protect against breast cancer when consumed in moderate amounts throughout life, as is common in the Asian diet (Figure F3.5). Increasing soy consumption after menopause may have no effect.[27]

© 4kodiak/iStockphoto

FIGURE F3.5 Soy isoflavones
A high intake of soy and soy products, such as this miso soup with tofu, throughout life is one factor that is believed to contribute to the health benefits of a traditional Asian diet.

F3.2 How to Choose a Phytochemical-Rich Diet

LEARNING OBJECTIVES

- List foods that are high in phytochemicals.
- Compare the health benefits of taking phytochemical supplements with those of a diet rich in unrefined plant foods.

It has not been possible to make quantitative recommendations for the intake of specific phytochemicals. Many of these substances have not been identified or classified. Many function differently depending on the form in which they are consumed. Their effects may vary if they are removed from the foods in which they are found. Therefore, to benefit the most from phytochemicals, choose a diet based on plant foods. The impact of the total diet is more significant than that of any single phytochemical. For example, in some people a diet high in plant sterols, soy, almonds, and foods such as oats, barley, psyllium, okra, and eggplant that are high in soluble fibers, has been shown to be as effective at lowering cholesterol as prescription medications.[28] Likewise, it has been hypothesized that a diet rich in flaxseed, cruciferous vegetables, and fruits and vegetables in general could significantly reduce the risk of breast, colon, prostate, lung, and other cancers.[29] Some suggestions for increasing the intake of foods that provide a variety of phytochemicals are given in **How to Choose: Phytochemicals**.

Eat More Fruits and Vegetables

The Dietary Guidelines and MyPlate recommend a diet with plenty of fruits and vegetables: 2 cups of fruit and 2.5 cups of vegetables for a 2000-kcal diet. If these include a rainbow of colors—dark green vegetables as well as yellow-orange, pale yellow, and deep red and purple fruits and vegetables—you are getting an abundance of carotenoids, flavonoids, and other phytochemicals (Figure F3.6).[30]

Unfortunately, most people do not follow these recommendations. Recent surveys of the typical American diet suggest that only about 13% of Americans consumes the recommended servings of fruits and only about 9% consumes the recommended servings of vegetables.[31] In addition, white potatoes represent a disproportionately large share of the total vegetable intake (many of these consumed as French fries), while phytochemical- and nutrient-rich dark green and deep yellow and orange vegetables accounted for a disproportionately small share.

HOW TO CHOOSE | **Phytochemicals**

- Choose five different colors of fruits and vegetables each day.
- Try a new fruit or vegetable each week.
- Spice up your food—herbs and spices are a great source of phytochemicals.
- Add vegetables to your favorite entrees such as spaghetti sauces and casseroles.
- Try baked or dried fruit for dessert.
- Double your typical serving of vegetables.
- Add pesto, spinach, artichokes, or asparagus to pizza.
- Buy jars of chopped garlic, ginger, and basil to make it easy to add more of these to your cooking.
- Snack on whole-grain crackers.
- Add barley or bulgur to casseroles or stews.
- Switch to whole-wheat bread, brown rice, and whole-wheat pasta.
- Add fruit to your cereal or vegetables to your eggs.
- Dice up some tofu and add it to your stir fry.
- Include nuts in stir fries and baked goods.
- Sprinkle flaxseed on your oatmeal.

Make Half Your Grains Whole

Fruits and vegetables aren't the only source of dietary phytochemicals. In fact, whole grains deliver as many—if not more—phytochemicals and antioxidants than do fruits and vegetables, and therefore MyPlate recommends that half our grains should be whole grains. Epidemiological studies have found that whole-grain intake is associated with a lower risk of cancer, cardiovascular disease, diabetes, and obesity. These health-promoting properties are believed to be due to the synergistic effects of the wide variety of nutrients and phytochemicals found in whole grains.[14] For example, whole grains are a good source of B vitamins, trace elements, and fiber, and are rich in antioxidant phytochemicals called phenols as well as phytate, phytoestrogens such as lignan, and plant stanols and sterols. The bran and germ portions of whole-wheat flour contribute more than half of the total phenols, flavonoids, lutein, and zeaxanthin, as well as over 80% of the water-soluble and fat-soluble antioxidant activity.[32] These phytochemicals and vitamins are lost when the bran and germ are removed to make white flour. The Dietary Guidelines recommend Americans consume at least three servings, or half of their grain servings, as whole grains. Very few Americans consume enough whole grains to meet the recommended intake.[30]

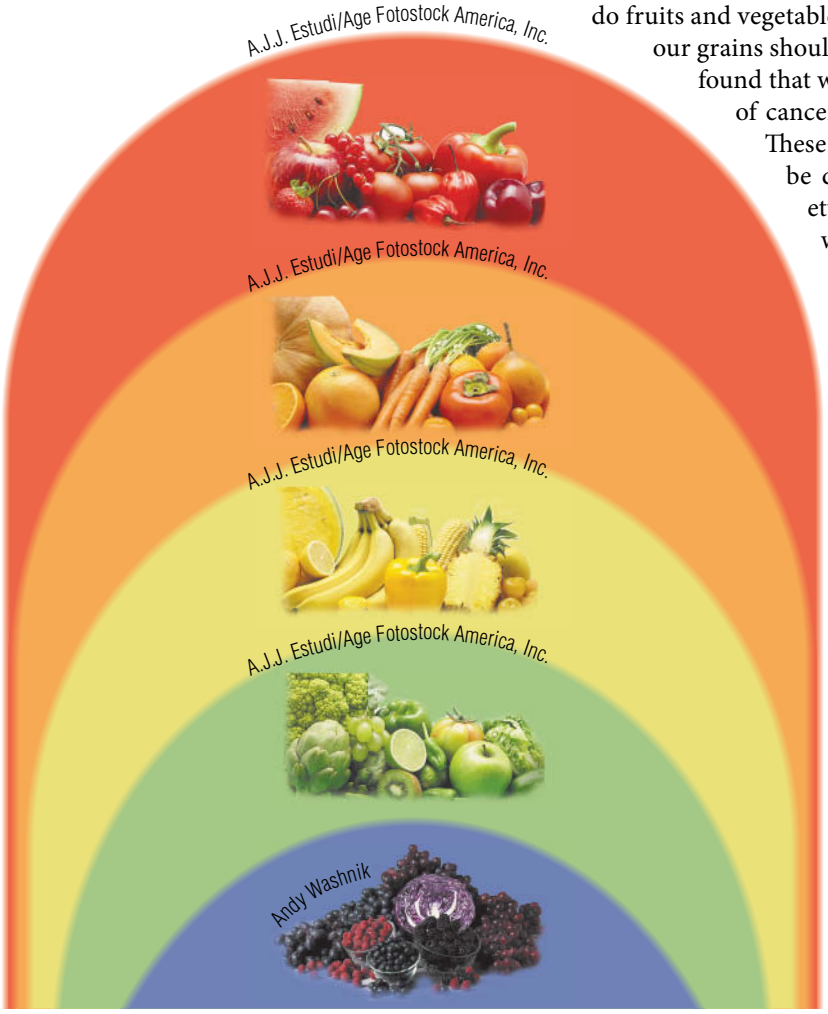


FIGURE F3.6 Eat a rainbow of fruits and vegetables
Choosing fruits and vegetables with all the colors of the rainbow is a good way to include a variety of phytochemicals in your diet.

Choose Plant Proteins

The amounts of health-promoting substances in the diet can further be enhanced by choosing plant sources of protein. Phytochemical-rich soybeans and flaxseed are good sources of protein and, other legumes, nuts, and seeds are high-protein foods that make important

fiber and phytochemical contributions. The Dietary Guidelines and MyPlate encourage the consumption of these high-phytochemical protein sources by recommending that Americans choose more beans, peas, nuts, and seeds.

Added versus Naturally Occurring Phytochemicals

In addition to foods that are natural sources of phytochemicals, phytochemical supplements are available and many foods are fortified with phytochemicals. For example, special margarines such as Benecol® and Take Control® contain added plant sterols to help lower blood cholesterol, some brands of oatmeal are fortified with soy and flaxseed, and carrot juice is available with added lutein. These modified foods have also been called *nutraceuticals* because they blur the line between nutrients and pharmaceuticals, or *designer foods* because they are designed to provide specific health benefits (see Chapter 8, *Debate: Super-Fortified Foods: Are They a Healthy Addition to Your Diet?*).

While phytochemical supplements and phytochemical-fortified foods may offer some specific advantages, they do not provide all the benefits obtained from a diet high in natural sources of these compounds. One reason is that most of these products contain only a few of the many phytochemicals found naturally. In addition, the benefits provided by consuming a variety of phytochemical-rich foods are believed to be due to the interactions among the many phytochemicals and nutrients, and therefore cannot be replicated by a supplement that contains only one or a few of these substances. Finally, the amounts that can be added to supplements or foods may be too small to have an impact on overall health. For example, a multivitamin advertising that it provides lycopene may include only about 0.3 mg per dose, whereas a half-cup serving of spaghetti sauce will give you about 20 mg.

CHAPTER OUTLINE

10.1 Water: The Internal Sea

How Water Functions in the Body

How Water Is Distributed Throughout the Body

10.2 Water Balance

Water Intake

Water Losses

Water Deficiency: Dehydration

Water Intoxication: Overhydration

Recommended Water Intake

10.3 Electrolytes: Salts of the Internal Sea

Sodium, Potassium, and Chloride in Our Food

How Sodium, Potassium, and Chloride Function in the Body

How Electrolyte Balance Is Regulated

Electrolyte Deficiency

Electrolyte Toxicity

10.4 Hypertension

What Causes Hypertension?

Factors That Affect the Risk of Hypertension

How Diet Affects Blood Pressure

10.5 Healthy Electrolyte Intakes

Recommended Sodium, Chloride, and Potassium Intakes

Choosing a Dietary Pattern to Lower Blood Pressure

(©iStockphoto)

Eiichi Onodera/Dex Image/Getty Images, Inc.

Water and the Electrolytes

10

CASE STUDY

When Gabriele Andersen-Scheiss emerged from the tunnel into the Olympic stadium in 1984 for the final lap of the women's marathon, she didn't look much like a world-class athlete. The 37-year-old runner staggered around the track as if drunk, her left arm limp, her right leg stiff. She had completed about 26 of the 26.2 miles of the marathon, but it wasn't clear whether she now could negotiate a single lap around the track. What was wrong? Should someone stop her?

Medical officers rushed over to help, but she waved them off. After observing her as she continued around the track, doctors decided to allow her to go on unaided. Andersen-Scheiss was demonstrating the signs of serious dehydration. Because the medics could see that she was sweating profusely, though, they concluded that she was not yet suffering from heat stroke, the most severe and life-threatening form of heat-related illness. The gold medalist in this race, Joan Benoit, had crossed the finish line 20 minutes earlier, so Andersen-Scheiss was struggling simply to finish, not to win. One minute the crowd was cheering her on, and the next they were pleading for the medics to stop her. Her final staggering lap around the track to the finish line lasted 5 minutes and 44 seconds. Medics immediately treated her for dehydration and heat exhaustion.

David Tenenbaum/©AP/Wide World Photos

This case illustrates the importance of water in maintaining body systems. Water and the minerals dissolved in it make up the soup in which the reactions that maintain life occur. **Water and mineral imbalances can come on rapidly and be devastating, but they can also be alleviated faster than other nutrient deficiencies.**

10.1 Water: The Internal Sea

LEARNING OBJECTIVES

- Describe the functions of water in the body.
- Discuss the forces that move water back and forth across cell membranes.

The complex molecules necessary for the emergence of life were forged in the Earth's first seas. These primordial seas supported life because they were rich in inorganic minerals as well as organic substances. As organisms grew in complexity, the water and chemicals critical to their survival were incorporated into an internal sea. Just as the right amounts of water, organic molecules, and minerals were necessary for the beginning of life, the right combination is necessary in the body for the maintenance of life. This internal sea allows the reactions necessary for life to proceed.

solvent A fluid in which one or more substances dissolve.

solutes Dissolved substances.

polar Used to describe a molecule that has a positive charge at one end and a negative charge at the other.

electrons Negatively charged particles.

ion An atom or group of atoms that carries an electrical charge.

dissociate To separate two charged ions.

How Water Functions in the Body

Water is an essential nutrient that we must consume in our diet to survive. In the body, water serves as a medium in which chemical reactions take place; it also transports nutrients and wastes, provides protection, helps regulate temperature, participates in chemical reactions, and helps maintain acid–base balance.

Why Water Is a Good Solvent One of the key functions of water in the body is as a **solvent**. A solvent is a fluid in which **solutes** can dissolve to form a solution. Water is an ideal solvent for some substances because it is **polar**; that is, the two sides or poles of the water molecule have opposite electrical charges. The polar nature of water comes from its structure, which consists of two hydrogen atoms and one oxygen atom (H_2O). These atoms, like all atoms, are made up of a positively charged central core, or nucleus, with negatively charged **electrons** orbiting around it. To form a water molecule, the two hydrogen atoms move close enough to share their electrons with an atom of oxygen. But the sharing is not equal. The shared electrons spend more time around the oxygen atom than around the hydrogen atoms, giving the oxygen side of the molecule a slightly negative charge and the hydrogen side a slightly positive charge. This polar nature of water allows it to surround other charged molecules and disperse them. Table salt, which dissolves in water, consists of a positively charged sodium **ion** (Na^+) bound to a negatively charged chloride ion (Cl^-). When placed in water, the sodium and chloride ions move apart, or **dissociate**, because the positively charged sodium ion is attracted to the negative pole of the water molecule and the negatively charged chloride ion is attracted to the positive pole (Figure 10.1).

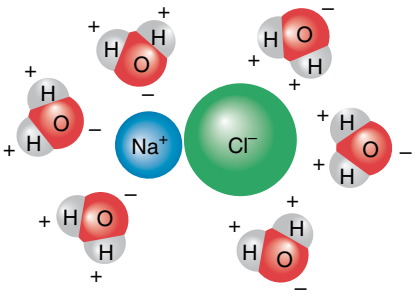


FIGURE 10.1 The polar nature of water
The oxygen (O) side of a water molecule has a slightly negative charge and the hydrogen (H) side has a slightly positive charge. This polar nature causes sodium chloride (NaCl) to dissolve when placed in water; the sodium (Na^+) and chloride (Cl^-) dissociate because the negative sides of the water molecules are attracted to the positively charged sodium ions and the positive sides of the water molecules are attracted to the negatively charged chloride ions.

Water Transports Materials Throughout the Body Blood, which is about 90% water, transports oxygen and nutrients to cells. It then carries carbon dioxide and other waste products away from the cells. Blood also distributes hormones and other regulatory molecules throughout the body so they can reach target cells. Water in urine helps to carry waste products, such as urea and ketones, out of the body.

Water Lubricates and Protects Water functions as a lubricant and cleanser. Watery tears lubricate the eyes and wash away dirt; synovial fluid lubricates the joints; and saliva lubricates the mouth, making it easier to chew, taste, and swallow food. Water inside the eyeballs and spinal cord acts as a cushion against shock. Similarly, during pregnancy, water in the amniotic fluid provides a protective cushion around the fetus.

Water Regulates Body Temperature Body temperature is closely regulated to maintain a normal level of around 98.6°F (37°C). If the body temperature rises above 108°F or falls below 80°F, death is likely. The fact that water holds heat and changes

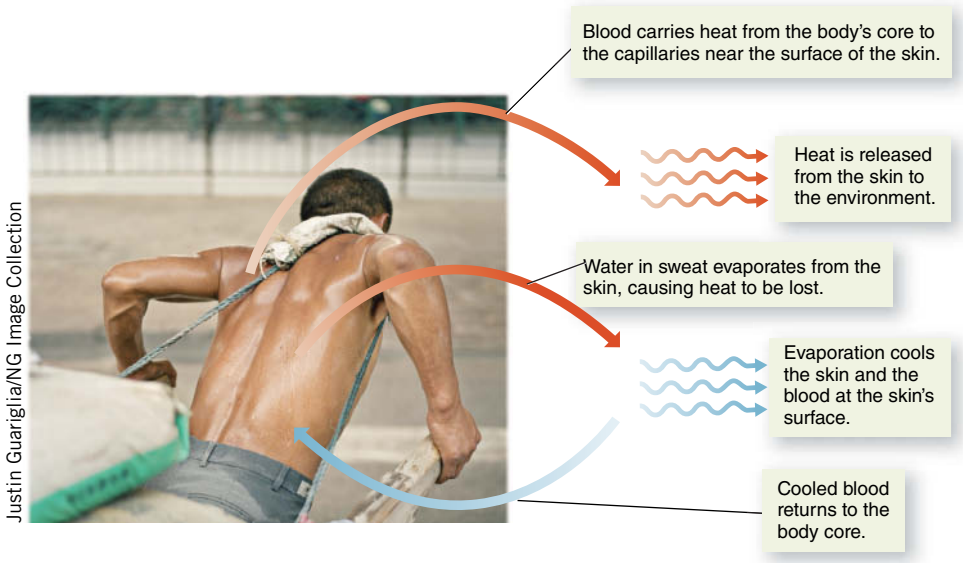


FIGURE 10.2 Water helps cool the body Shunting blood to the skin allows heat to be transferred from the blood to the surroundings. Evaporation of the water in sweat cools the skin and the blood near the surface of the skin.

temperature slowly helps keep body temperature constant when the outside temperature fluctuates, but water is also more actively involved in temperature regulation.

The water in blood helps regulate body temperature by increasing or decreasing the amount of heat lost from the surface of the body. When body temperature starts to rise, the blood vessels in the skin dilate, causing blood to flow close to the surface of the body where it can release some of the heat to the environment (Figure 10.2). This occurs with fevers, as well as when environmental temperature rises. In a cold environment, blood vessels in the skin constrict, restricting the flow of blood near the surface and conserving body heat.

Water also helps regulate body temperature through evaporation. When body temperature increases, the brain triggers the sweat glands in the skin to produce sweat, which is mostly water. As the water evaporates from the skin, heat is lost, cooling the body (see Figure 10.2).

Water Participates in Metabolic Reactions Water is involved in some of the chemical reactions of metabolism. Hydrolysis reactions break large molecules into smaller ones by adding water. For example, water is added in the reaction that breaks a molecule of maltose into two glucose molecules (see Figure 4.6) as well as the reactions that break the peptide bonds that hold amino acids together. Water also participates in reactions that join two molecules. These reactions, called dehydration reactions, are a type of condensation reaction, in which a molecule of water is lost. The formation of the disaccharide maltose from two glucose molecules and the formation of a peptide bond between two amino acids are dehydration reactions, and therefore involve the removal of a water molecule.

Water Helps Maintain Acid–Base Balance The chemical reactions that occur in the body are very sensitive to acidity. Acidity is expressed in units of **pH**. The range of pH units is from 1 to 14, with 1 being very acidic, 14 being very basic or alkaline, and 7 being neutral (Figure 10.3). Most reactions in the body occur in slightly basic solutions, around pH 7.4. If body solutions become too acidic or too basic, chemical reactions cannot proceed efficiently. Water and the dissolved substances it contains are important for maintaining the proper level of acidity. Water serves as a medium for the chemical reactions that prevent changes in pH, and it participates in some of these reactions. Water is also needed as a transport medium to allow the respiratory tract and kidneys to regulate acid–base balance.

pH A measure of the level of acidity or alkalinity of a solution.

How Water Is Distributed Throughout the Body

Water is found in varying proportions in all the tissues of the body; blood is about 90% water, muscle about 75%, and bone about 25%. Adipocytes have a low water content—only about 10%. In adults, about 60% of total body weight is water, but this varies with age and other factors that affect body composition.

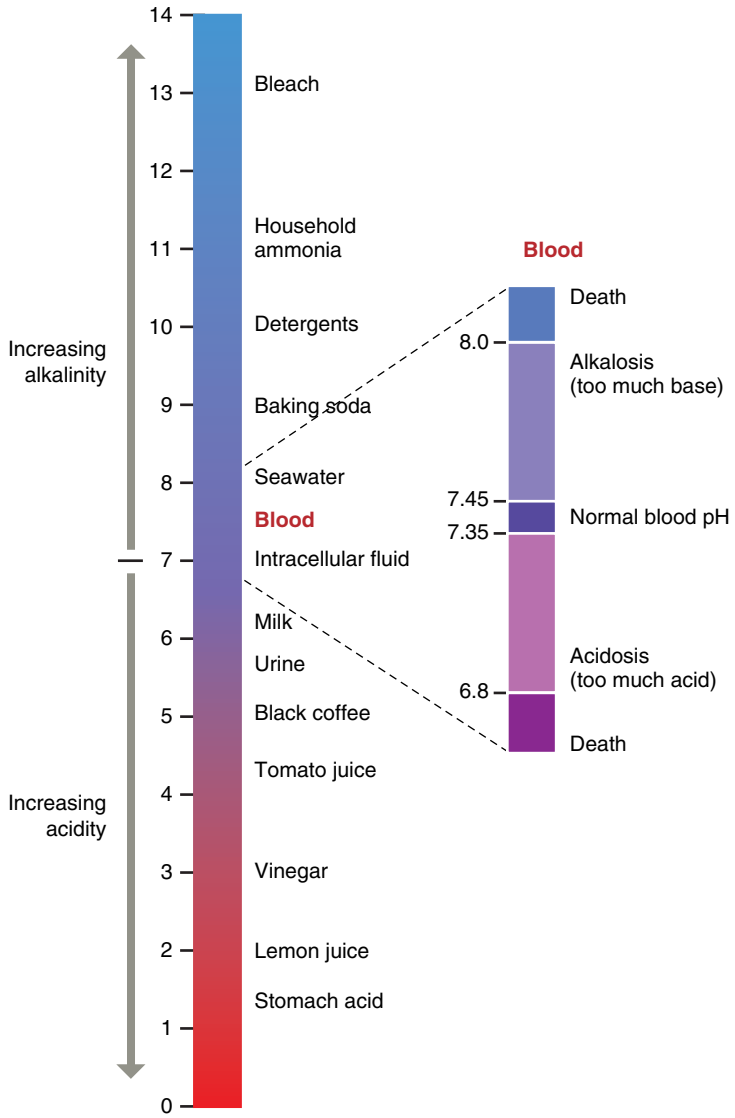


FIGURE 10.3 pH values of common fluids
The normal range of blood pH is very narrow: 7.35 to 7.45. A pH below (acidosis) or above (alkalosis) this range prevents chemical reactions from occurring normally in the body. If severe, deviations in pH can be fatal.

intracellular fluid The fluid located inside cells.

extracellular fluid The fluid located outside cells. It includes fluid found in the blood plasma, lymph, gastrointestinal tract, spinal column, eyes, and joints and that found between cells.

interstitial fluid The portion of the extracellular fluid located in the spaces between the cells of body tissues.

blood pressure The amount of force exerted by the blood against the artery walls.

The percentage of water is higher in infants than in adults and decreases as adults age, primarily due to increases in body fat and a loss of muscle, which is high in water. Because women typically have a higher percentage of body fat than men, they have less body water. Individuals who are obese have a lower percentage of body weight as water and a higher percentage as fat than their lean counterparts.

About two-thirds of body water is found inside cells; this is known as **intracellular fluid**. The remaining one-third is outside cells as **extracellular fluid**. Extracellular fluid includes primarily blood plasma, lymph, and the fluid between cells, called **interstitial fluid**. Other extracellular fluids include fluid secreted by glands, such as saliva and other digestive secretions, and fluid in the eyes, joints, and spinal cord. The concentration of substances dissolved in body water varies among these body compartments. The concentration of protein is highest in intracellular fluid, lower in blood plasma, and even lower in interstitial fluid. Extracellular fluid has a higher concentration of sodium and chloride and a lower concentration of potassium, and intracellular fluid is higher in potassium and lower in sodium and chloride.

The movement of water from one compartment to another is affected by fluid pressure and osmosis (Figure 10.4). The fluid pressure of blood against the blood vessel walls, or **blood pressure**, causes water to move from the blood into the interstitial space. The difference in the concentration of solutes between the blood in the capillaries and the fluid in the interstitial space causes much of this water to reenter the capillaries by osmosis (see Chapter 3). Osmosis occurs when a selectively permeable membrane, such as a cell membrane, allows water to pass freely but regulates the passage of other substances. Water moves across this membrane in a direction that

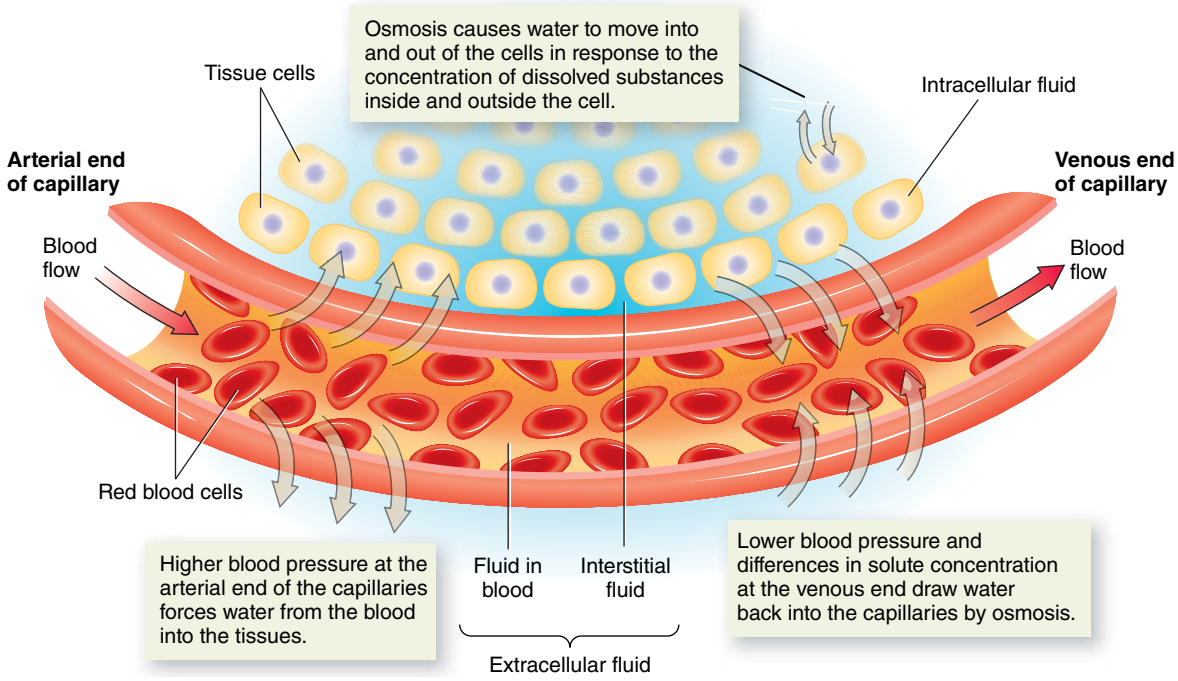


FIGURE 10.4 Forces that distribute body water
The amount of water in blood and tissues is determined by blood pressure and the force generated by osmosis.

will equalize the concentration of solutes on both sides (Figure 10.5). The body can regulate the amount of water in each compartment by adjusting the concentration of solutes and relying on osmosis to move water.

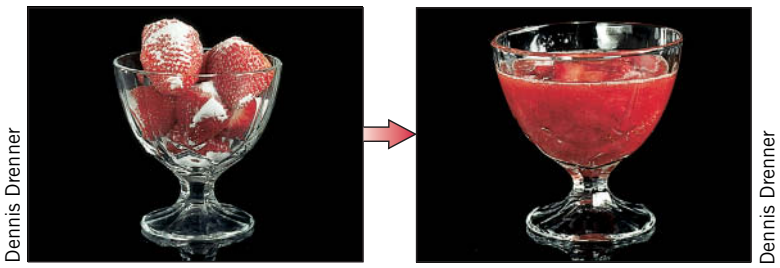


FIGURE 10.5 Osmosis
When sugar is sprinkled on fresh strawberries, the water inside the strawberries moves across the skin of the fruit to try to equalize the sugar concentration on each side. This pulls water out of the fruit and causes it to shrink.

THINK CRITICALLY

Draw an illustration showing the concentration of water molecules and sugar molecules inside and outside the strawberries in each of these photos.

10.2 Water Balance

LEARNING OBJECTIVES

- Discuss how water intake is regulated.
- Describe the routes by which water is lost and how losses are regulated.
- Compare the causes and effects of dehydration and overhydration.
- List factors that affect water requirements.

The amount of water in the body remains relatively constant over time. And, because the body does not store water, in order to maintain homeostasis, the water taken into the body must equal the amount of water lost from the body in urine, in feces, and through evaporation

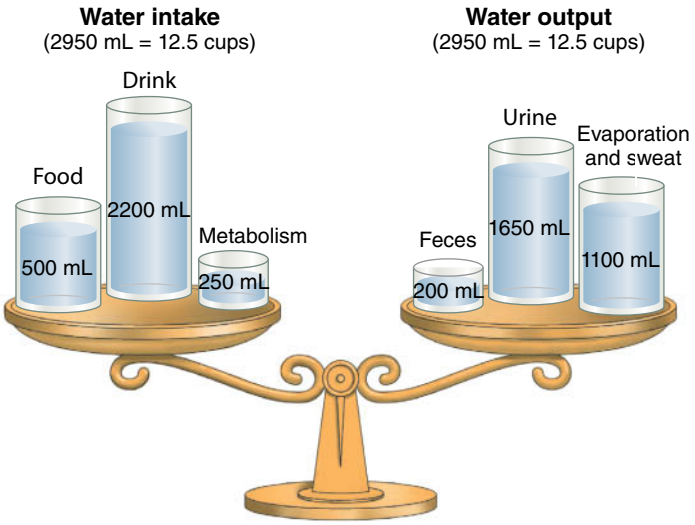


FIGURE 10.6 Water balance
To maintain water balance, intake from food and drink and water produced by metabolism must equal water output from evaporation, sweat, urine, and feces. This figure illustrates approximate amounts of water that enter and leave the body daily in a typical woman in a temperate environment who is in water balance.

(Figure 10.6). When water losses are increased, as they are in hot weather and with exercise, intake must increase to keep body water at a healthy level. Even minor changes in the amount and distribution of body water can be life threatening.

Water Intake

Most of the water in the body comes from the diet—not only as water we drink but also from the water in other liquids and in solid food (Figure 10.7). About 75 to 80% of total water intake comes from fluids, with food providing the remaining 20 to 25%.[1] Milk is about 90% water, apples are about 85% water, and roast beef is about 50% water. A small amount of water is also generated inside the body by metabolism, but this is not significant in meeting body water needs.

Water Absorption Water consumed in the diet is absorbed from the gastrointestinal tract by osmosis. This is possible because of the concentration gradient created by the absorption of nutrients from the lumen into the blood. As nutrients are absorbed, the solute concentration in the lumen decreases. Water therefore moves with the absorbed nutrients toward the area with the highest solute concentration. The rate of water absorption is affected by the volume of water and the concentration of nutrients consumed with it. Consuming a large volume of water increases the rate of water absorption; increasing the nutrients and other solutes it contains decreases the rate of absorption.

How Water Intake Is Regulated The need to consume water is triggered by the sensation of thirst. Thirst is caused by dryness in the mouth as well as by signals from the brain (Figure 10.8). In general, fluid intake driven by thirst is adequate to maintain water homeostasis. However, people don't or can't always drink when they are thirsty, and thirst is quenched almost as soon as fluid is consumed and long before short-term water balance is restored. When water losses are rapid, such as might occur in an athlete exercising in hot weather, or a person with fever, vomiting, or

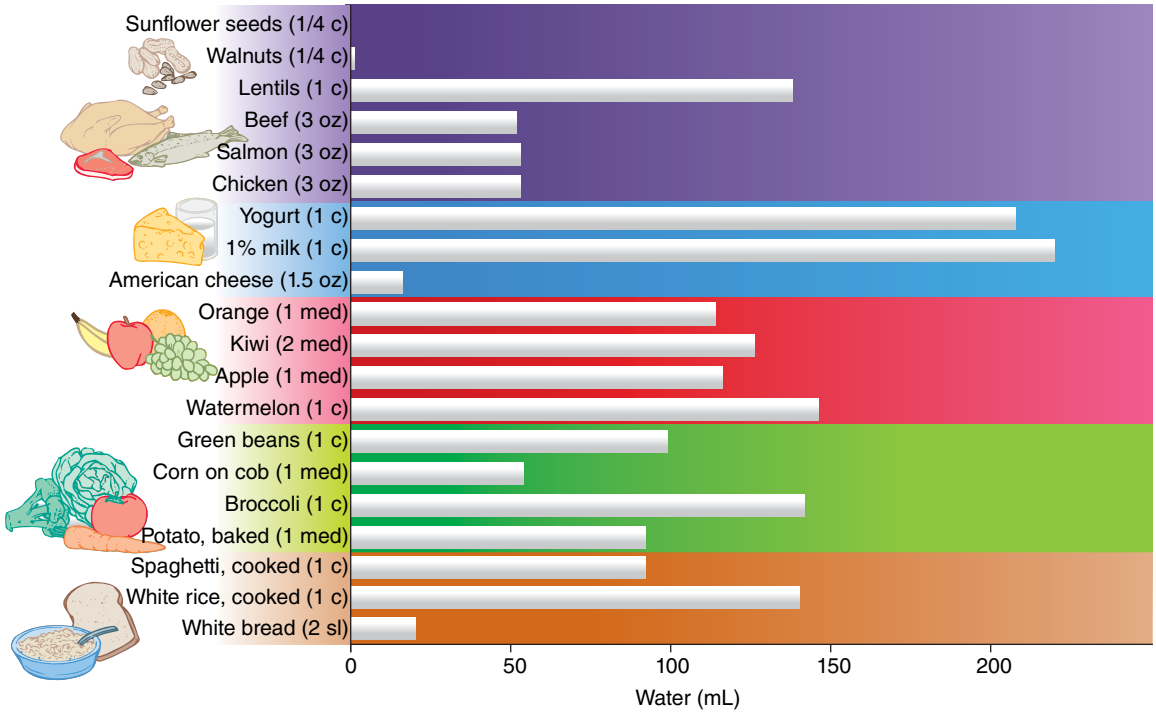


FIGURE 10.7 Sources of water in MyPlate food groups
Fruits and vegetables, as well as many choices from other food groups, have a high water content.

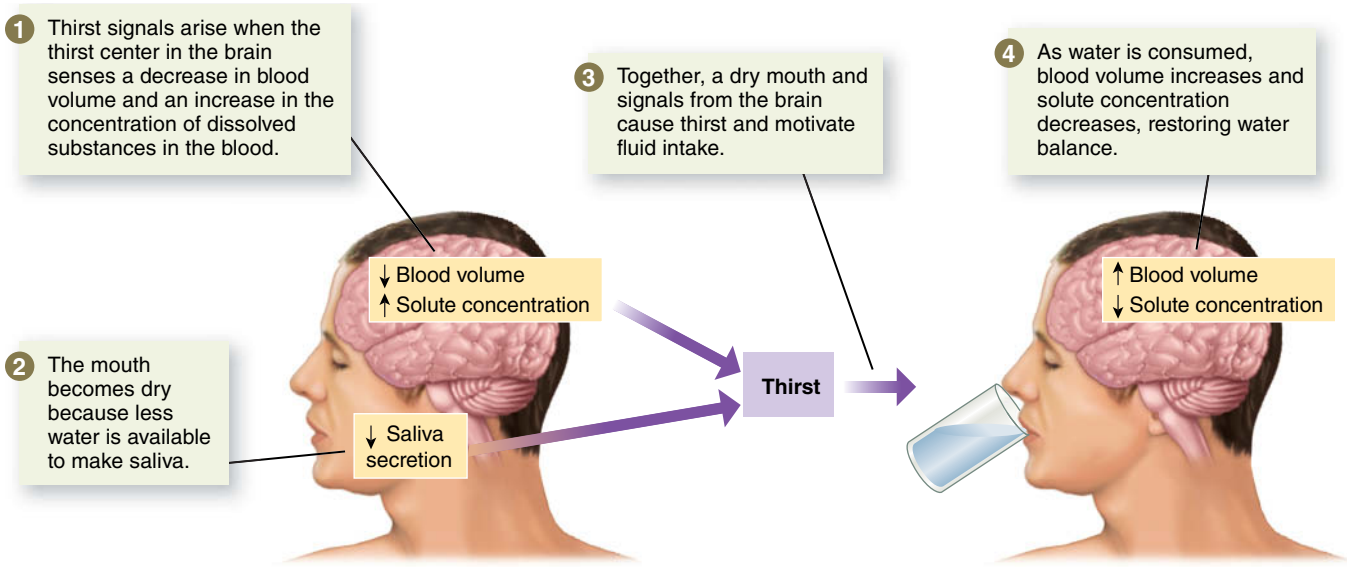


FIGURE 10.8 Stimulating water intake
The sensation of thirst helps motivate fluid intake in order to restore water balance.

diarrhea, thirst mechanisms may not be adequate to replace the lost fluid. Thirst is a powerful urge, but to maintain adequate levels of water in the body it is also necessary to regulate water excretion.

Water Losses

Water is lost from the body in urine, in feces, through evaporation from the lungs and skin, and in sweat. A typical adult who is not sweating loses about 2.7 to 3.7 liters (L), or about 11.5 to 15.5 cups, of water daily (see Figure 10.6).[1]

Urinary Losses Typical urine output is 1 to 2 L/day (about 4 to 8 cups/day), but the amount of water lost in the urine varies with water intake (drinking more proportionately increases urine output) and the amount of waste that needs to be excreted in the urine. The waste products that must be excreted in urine include urea and other nitrogen-containing products from protein breakdown, ketones from fat breakdown, phosphates, sulfates, sodium, and other minerals. The amount of urea that must be excreted is increased when dietary protein increases or body protein breakdown increases. Ketone excretion is increased when body fat is broken down. In both cases, the need for water increases in order to produce more urine to excrete the extra wastes.

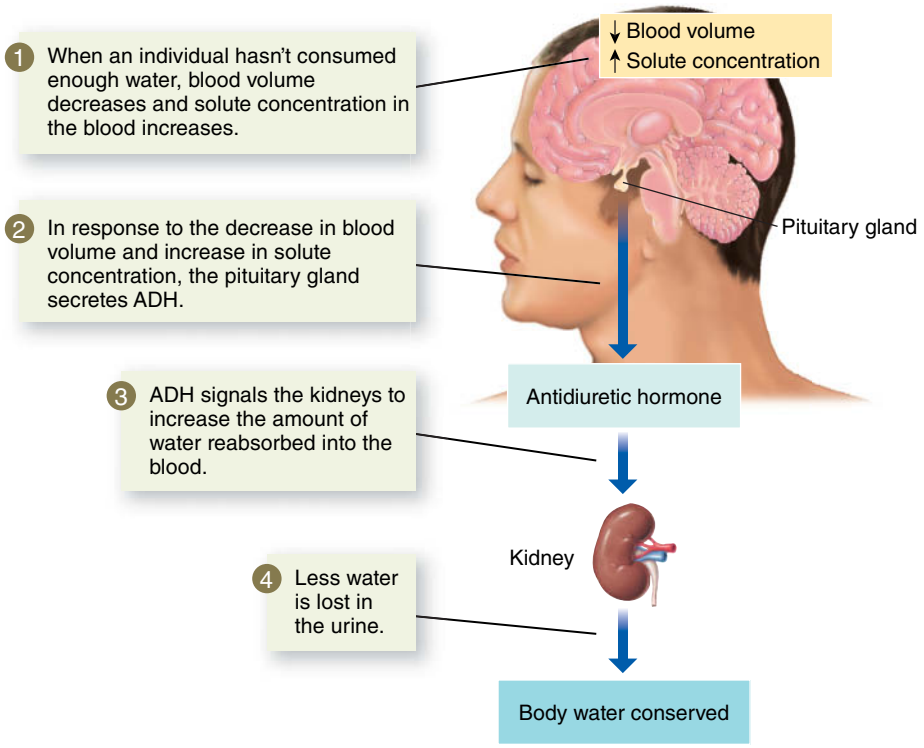
Fecal Losses In a healthy person, the amount of water lost in the feces is usually small, only about 200 mL/day (less than a cup). This is remarkable because every day about 9 L (38 cups) of fluid enter the gastrointestinal tract via food, water, and secretions. Under normal conditions, more than 95% is reabsorbed before the feces are eliminated. However, in cases of severe diarrhea, large amounts of water can be lost through the gastrointestinal tract and can compromise health.

Evaporative Losses People are continuously losing water from their skin and respiratory tract due to evaporation. This occurs without the individual being aware that it is occurring; such losses are therefore referred to as **insensible losses**. The amount of water lost through evaporation varies greatly, depending on activity, temperature, humidity, and body size. In a temperate climate, an inactive person loses about 1 L (about 4 cups) per day through insensible losses; the amount increases with increases in activity, environmental temperature, and body size, as well as when humidity is low, as in an airplane or in the desert.

insensible losses Fluid losses that are not perceived by the senses, such as evaporation of water through the skin and lungs.

Sweat Losses In addition to losing water through evaporation, people lose water in sweat when they exercise and when the environment is hot. More sweat is produced as exercise intensity increases and as the environment becomes hotter and more humid. An individual doing light work at a temperature of about 84°F will lose about 2 to 3 L (about 8 to 12.5 cups) of sweat per day. Strenuous exercise in a hot environment can cause water losses in sweat to be as high as 2 to 4 L (about 8 to 17 cups) in an hour.[2] Clothing that permits the evaporation of sweat helps keep the body cool and therefore decreases the amount of sweat produced. Adequate water intake is

FIGURE 10.9
Regulating urinary water losses
The kidneys help regulate water balance by adjusting the amount of water lost in the urine in response to the release of antidiuretic hormone (ADH).



THINK CRITICALLY

What happens to ADH levels and urine volume if someone consumes a lot of extra water?

essential to compensate for these losses. Athletes can estimate water loss by weighing themselves before and after exercise. Lost water can then be replaced by consuming at least the equivalent weight in fluids. For instance, an athlete who loses 2 lb during a workout should consume an extra 2 to 4 pints or 1 to 2 L of fluid (1 lb = 1 pint, or about one-half liter) (see Chapter 13).

How Water Losses Are Regulated To maintain water balance, the kidneys regulate the amount of water excreted in the urine. The kidneys function like a filter. As blood flows through them, water molecules and other small molecules move through the filter and out of the blood, while blood cells and large molecules are retained in the blood. Some of the water and other molecules that are filtered out are reabsorbed into the blood, and the rest are excreted in the urine.

antidiuretic hormone (ADH) A hormone secreted by the pituitary gland that increases the amount of water reabsorbed by the kidney and therefore retained in the body.

The amount of water that is reabsorbed into the blood rather than excreted in the urine depends on conditions in the body. When the concentration of solutes in the blood is high, as in someone who has exercised strenuously and not consumed enough water, **antidiuretic hormone (ADH)**, which is secreted from the pituitary gland, signals the kidneys to reabsorb water to reduce the amount lost in the urine. This reabsorbed water is returned to the blood, preventing the solute concentration in the blood from increasing further (Figure 10.9). When the solute concentration in the blood is low, as in someone who has just guzzled several glasses of water, ADH levels decrease. Now the kidneys reabsorb less water and more is excreted in the urine, allowing blood solute concentration to increase to normal. The amount of sodium in the blood, blood volume, and blood pressure also play a role in regulating body water.

Water Deficiency: Dehydration

dehydration A condition that results when not enough water is present to meet the body's needs.

Dehydration occurs when water loss exceeds water intake. It causes a reduction in blood volume, which impairs the body's ability to deliver oxygen and nutrients to cells and remove waste products. The symptoms of dehydration occur more rapidly than do symptoms for any other nutrient deficiency. Early symptoms include headache, fatigue, loss of appetite, dry eyes and mouth, and dark-colored urine (Figure 10.10). A level of dehydration corresponding to a body water loss of 2% of body weight or greater can impair physical and cognitive performance and affect mood.[3,4] A loss of 5% of body weight as water can cause nausea and difficulty concentrating. Confusion and disorientation can occur when water loss approaches 7% of body weight. A loss of about 10 to 20% can be fatal. Without water, an average person can survive for only a few days, compared to about eight weeks without food.

Chronic mild dehydration also impairs health. It can increase the risk of kidney stones and urinary tract infections.[5] It also causes prolonged constriction of the blood vessels, which can increase the risk of high blood pressure and stroke.[6]

Athletes are at risk for dehydration because they may lose large amounts of water in sweat. Older adults are at risk because the thirst mechanism becomes less sensitive with age and kidney function is more likely to be impaired, resulting in less efficient conservation of water. Infants are at risk because their body surface area relative to their weight is much greater than that of adults, so they lose proportionately more water through evaporation; also, their kidneys cannot concentrate urine efficiently, so they lose more water in urine. Infants and young children cannot express their thirst so must depend on caregivers to provide for their fluid needs.

The milder symptoms of dehydration disappear quickly after water or some other beverage is consumed. More severe dehydration can require medical attention. Dehydration due to diarrhea is a leading cause of death in children under 5 years old in the developing world. Replacing lost fluids and electrolytes in the right combinations can save lives. In some cases, oral rehydration therapy is sufficient. Drinking mixtures made by simply dissolving a large pinch of salt (½ tsp) and a scoop of sugar (2 T) in 1 L of clean water can restore the body's water balance by promoting the absorption of water and sodium. In severe cases of diarrhea, administration of intravenous fluids is needed to restore hydration (Figure 10.11).

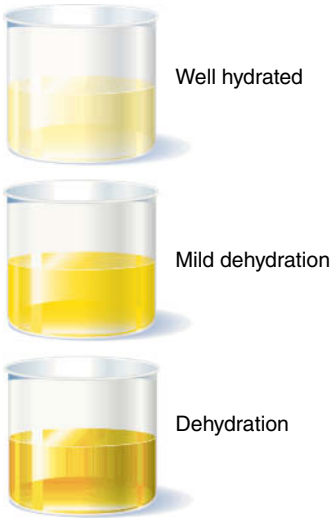


FIGURE 10.10 Are you at risk for dehydration?
Urine color is an indication of whether you are drinking enough. Pale yellow urine indicates you are well hydrated. The darker the urine, the greater the level of dehydration.

Water Intoxication: Overhydration

It is difficult to consume too much water under normal circumstances. However, overhydration or **water intoxication** may occur with illness and during exercise, particularly when exercise lasts several hours and fluids are replaced with plain water. An excess of water can affect the distribution of water among body compartments. When the blood has too much water relative to the amount of sodium (a condition called **hyponatremia**), water moves out of the blood vessels into the tissues by osmosis, causing them to swell. Swelling in the brain can cause disorientation, convulsions, coma, and death. Water intoxication and hyponatremia are far less common than dehydration but can be just as dangerous.

The early symptoms of water intoxication may be similar to dehydration: nausea, muscle cramps, disorientation, slurred speech, and confusion. It is important to determine if the problem is dehydration or water intoxication because if you assume the symptoms are from dehydration and drink plain water, the symptoms will worsen and can result in seizure, coma, or death. To help avoid water intoxication when exercising for more than an hour, beverages such as sports drinks, containing dilute solutions of sodium as well as sugar, should be used to replace water losses (see Chapter 13).

water intoxication A condition that occurs when a person drinks enough water to lower the concentration of sodium in the blood significantly.

hyponatremia Low blood sodium concentration.

Joe Raedle/Staff/Getty Images, Inc.

FIGURE 10.11 Rehydration saves lives
Oral rehydration solutions maximize the rate of water absorption. However, when water losses are too severe, intravenous (IV) fluids may be necessary. Administering IV fluids bypasses the gastrointestinal tract and puts fluid directly into the blood.

THINK CRITICALLY

Why would a solution of 0.9% sodium chloride in water be preferred over plain water as an intravenous fluid?

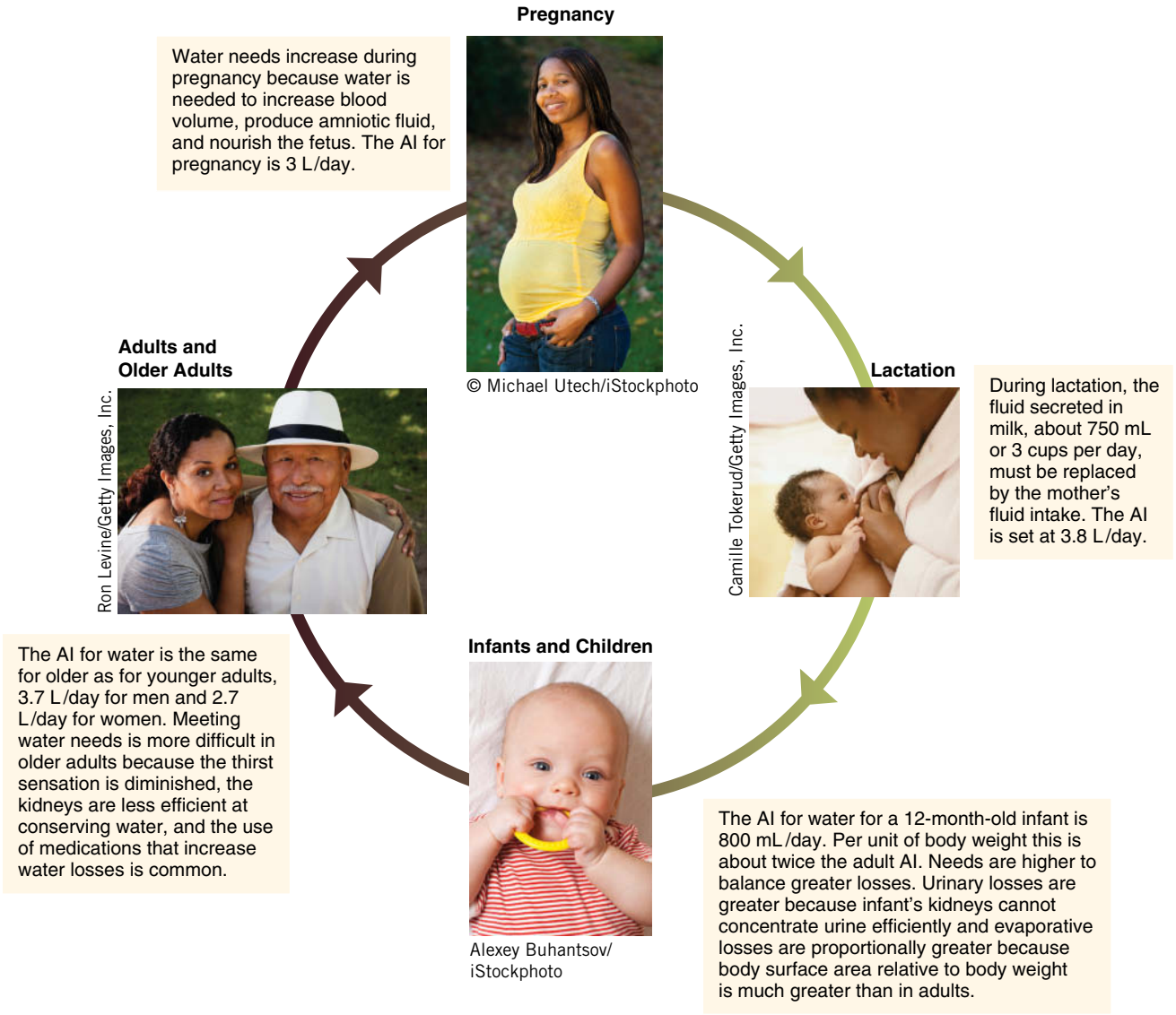
Recommended Water Intake

The actual amount of water needed by an individual each day can vary greatly depending on activity level, environmental temperature, and humidity. Despite this, AIs have been set for water: 3.7 L (15.5 cups) per day for adult men and 2.7 L (11.5 cups) per day for adult women. Figure 10.12 illustrates how needs change throughout life.[1]

Diet can also affect water needs. A high-protein diet increases water needs because the urea produced from protein breakdown is excreted in the urine. A low-calorie diet increases water needs because as body fat and protein are broken down to fuel the body, ketones and urea are produced and must be excreted in the urine. A high-sodium diet increases water losses because the excess sodium must be excreted in the urine. A high-fiber diet increases water needs because more water is held in the intestines and lost in the feces. Despite variations in our water needs, most people consume adequate fluids on a day-to-day basis to maintain body water at a normal level.[1]

In the United States, beverages provide about 80% of the body's requirement for water—about 3 L (12.5 cups) for men and 2.2 L (9 cups) for women.[1] The rest comes from the water consumed in food. Most beverages, whether water, milk, juice, or soda, help meet the overall need for water (see **Debate: Is Bottled Water Better?**). Beverages containing caffeine, such as coffee, tea, and cola, increase water losses for a short period because caffeine is a diuretic. Over the course of a day, however, the increase in water loss is small, so the net amount of water that caffeinated beverages add to the body is similar to the amount contributed by noncaffeinated beverages. Alcohol is also a diuretic; its overall effect on water balance depends on the relative amounts of water and alcohol in the beverages being consumed.[1]

FIGURE 10.12 Water needs throughout the life cycle



DEBATE

Is Bottled Water Better?

Americans consume almost 32 gallons of bottled water per person per year (see graph).[7] We choose it because it is convenient and because we think it tastes better and is safer than tap water. But the cost to our pocketbooks and our environment is high. Should we be filling our bottles at the tap instead?

© Skip ODonnell/iStockphoto

It is easy to grab a bottle of water, and most bottled water has no chlorine or other unpleasant aftertaste. Words like *pure, crisp*, and *fresh tasting* on the label lead consumers to buy bottled water because they think it is better than water that comes from the tap. But much of the bottled water sold in the United States is tap water that has been filtered, disinfected, or otherwise treated. By definition, bottled water can be any water, as long as it has no added ingredients (except antimicrobial agents or fluoride). Labels may help you distinguish: Distilled water and purified water are treated tap water; artesian water, spring water, well water, and mineral water come from underground sources.

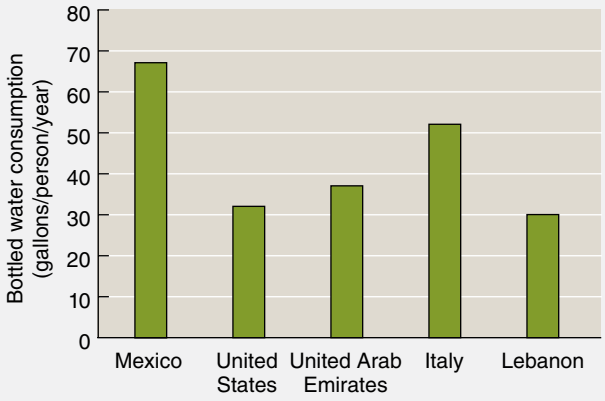
Is bottled water safer than tap water? Municipal (tap) water is regulated by the Environmental Protection Agency (EPA), and bottled water sold in interstate commerce is regulated by the Food and Drug Administration (FDA). The FDA uses most of the EPA's tap water standards, so it would make sense that tap water and bottled water would be equally safe. However, tap water advocates argue that tap water may actually be safer. A certified outside laboratory tests municipal water supplies every year, while bottled water companies are permitted to do their own tests for purity.[8] Tap water must also be filtered and disinfected, but there are no federal filtration or disinfection requirements for bottled water.

Contamination is a safety concern for both bottled water and tap water. A study of contaminants in bottled water found that 10 popular brands contained a total of 38 chemical pollutants—everything from caffeine and Tylenol to bacteria, radioactive isotopes, and fertilizer residue.[9] Sounds scary, but bottled water advocates argue that public drinking water may also fall short of pollutant standards. Since 2004, testing by water utilities has found over 300 pollutants in tap water. Some of these are substances that are regulated and were found at levels above guidelines, but more than half of the chemicals detected are not subject to health or safety regulations and can legally be present in any amount.[10]

One of the strongest arguments against bottled water is the cost, both to the consumer and the environment. Bottled water typically costs about $7.50 per gallon—almost 2000 times the cost of a gallon of tap water.[11] Bottled water drinkers may feel that the added cost is worth it because of the advantages in terms of taste and convenience. Opponents argue that even if you can afford it, the planet can't. Americans consume about 50 billion bottles of water per year, but only about 23% of these bottles are recycled. Manufacturing the bottles consumes more than 17 million barrels of oil annually, and this does not include the gasoline and jet fuel used to transport them.[12] Proponents of bottled water argue that despite the large amount of plastic waste, discarded water bottles still represent less than 1% of total municipal waste. And even though bottled water production is more energy intensive than the production of tap water, it makes up only a small share of total U.S. energy demand.[8]

So which is better? In the United States, bottled water and tap water are both generally safe. If you recycle your bottle, does it matter which you choose?

THINK CRITICALLY: Suggest factors that might increase a country's per capita consumption of bottled water?



The graph compares the per capita bottled water consumption in the United States to several other countries.

10.3 Electrolytes: Salts of the Internal Sea

LEARNING OBJECTIVES

- Define *electrolyte* in terms of nutrition.
- Contrast the dietary sources of sodium and potassium.
- Describe how electrolytes function in fluid balance, nerve conduction, and muscle contraction.
- Summarize how renin, angiotensin II, and aldosterone are involved in blood pressure regulation.
- Give an example of a situation or condition that might lead to electrolyte imbalance.

The water in the body—the internal sea—contains a variety of mineral salts. The right amounts and combinations of these are necessary for the maintenance of life. The distribution of these minerals affects the distribution of water in different body compartments. The properties of these minerals, including electrical charge, affect nerve and muscle function. Mineral salts dissociate in water to form ions. Positively and negatively charged ions are called **electrolytes**. Although there are many electrolytes in the body, in nutrition the term is typically used to refer to the three principal electrolytes in body fluids: sodium, potassium, and chloride. Sodium and potassium carry a positive charge, and chloride carries a negative charge.

electrolytes Positively and negatively charged ions that conduct an electrical current in solution. Commonly refers to sodium, potassium, and chloride.

Sodium, Potassium, and Chloride in Our Food

Much of the sodium we consume is in the form of sodium chloride, what we call salt or table salt. Salt is 40% sodium and 60% chloride by weight, so 9 grams (g) of salt contains 3.6 g of sodium (9 g × 0.4 = 3.6 g) and 5.4 g of chloride (9 g × 0.6 = 5.4 g). The U.S. diet is high in sodium and low in potassium. The reason is that we eat a lot of processed foods, which are high in sodium and generally low in potassium, and too few fresh unprocessed foods such as fruits, vegetables, whole grains, and fresh meats, which are low in sodium and high in potassium (Figure 10.13).

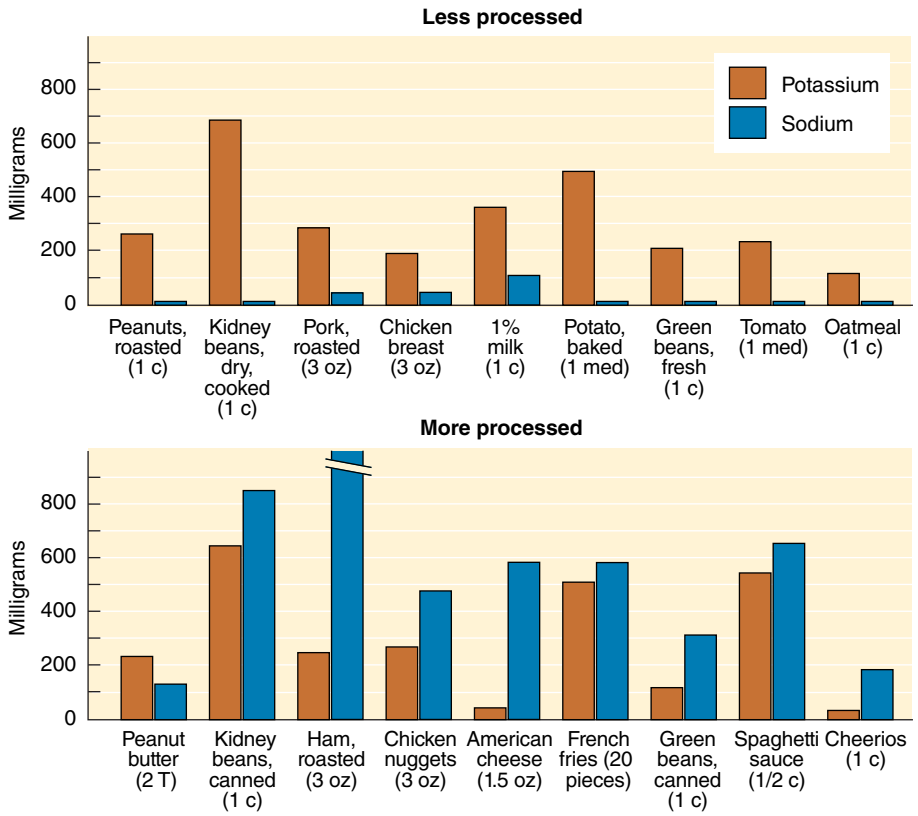


FIGURE 10.13 Sodium and potassium in processed and unprocessed foods Less processed foods tend to be low in sodium and good sources of potassium, whereas more processed foods are generally higher in sodium and may also be lower in potassium.

About 77% of the sodium Americans eat is from that added to food during processing and manufacturing. Only about 12% comes from sodium found naturally in food, while 11% is from salt added in cooking and at the table.[1] Less than 1% of the sodium we consume is from tap water.[1] Softened water or mineral water is often higher in sodium than tap water and, if consumed in large quantities, can contribute significantly to daily sodium intake. Some processed foods, such as potato chips, lunchmeats, and canned soups, contain large amounts of added sodium. Others, such as bread, have smaller amounts but add a lot of sodium to the diet because they are consumed frequently. Sodium is added to processed foods for flavoring and as a preservative because it inhibits bacterial growth. In addition to sodium chloride, other sodium salts, such as sodium bicarbonate, sodium citrate, and sodium glutamate, are also used as preservatives.

The human diet has not always been high in salt. Prehistoric diets consisted of unprocessed plant and animal foods such as nuts, berries, roots, greens, meat, and fish. These foods are high in potassium and low in sodium. Because of its value as a food preservative and flavor enhancer, salt was highly prized by ancient cultures in Asia, Africa, and Europe, where it was used in rituals as well as in the preservation of food. Roman soldiers were paid in *sal*, the Latin word for salt from which we get our word *salary*. Today, rather than a prized commodity, salt is a substance we attempt to limit in the diet. The reason for restricting salt is that diets high in salt have been implicated as a risk factor for **hypertension**.

hypertension Blood pressure that is consistently elevated to 140/90 millimeters of mercury (mm Hg) or greater.

How Sodium, Potassium, and Chloride Function in the Body

Almost all of the sodium, potassium, and chloride consumed in the diet is absorbed. In the body, these electrolytes help regulate fluid balance and are important for nerve conduction and muscle contraction. The functions of sodium, potassium, and chloride are so intertwined that they are discussed together in the following sections.

How Electrolytes Regulate Fluid Balance The distribution of fluid among body compartments depends on the concentration of electrolytes and other solutes. Water moves by osmosis in response to solute concentration. All body fluids are in osmotic balance. So, for example, a change in the concentration of solutes in the blood causes a shift in water that affects blood volume as well as interstitial and intracellular fluid volumes. The concentration of specific electrolytes in body compartments differs dramatically. Potassium is the principal positively charged ion inside cells, where it is 30 times more concentrated than outside the cell. Sodium is the most abundant positively charged electrolyte in the extracellular fluid, and chloride is the principal negatively charged extracellular ion.

The different intracellular and extracellular concentrations of these electrolytes are maintained by cell membranes and an active transport system called the *sodium-potassium-ATPase,* or *sodium-potassium pump*. Cell membranes keep the majority of sodium outside the cell and potassium inside, but some sodium and potassium do leak across the membrane. The sodium-potassium pump maintains the concentration gradient by pumping sodium out of the cell and pumping potassium into the cell (Figure 10.14). Maintaining this concentration gradient of electrolytes is important for nerve conduction and muscle contraction, but requires a great deal of energy: It is estimated that the sodium-potassium pump accounts for 20 to 40% of resting energy expenditure in an adult. The pumping of sodium ions across cell membranes is also linked to nutrient transport. For example, glucose and amino acids are transported by systems that depend on the movement of sodium ions across cell membranes.

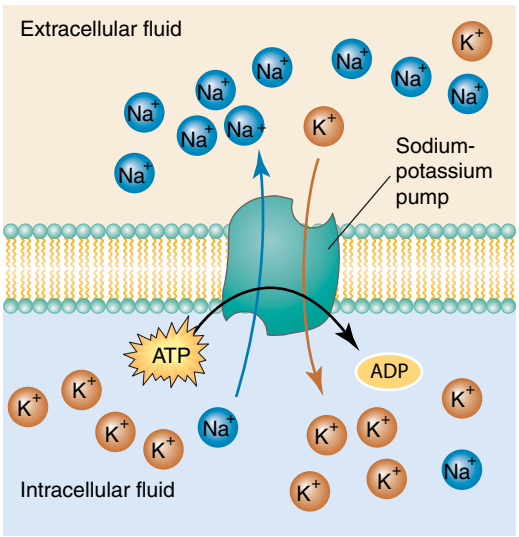


FIGURE 10.14 Sodium-potassium pump
Each cycle of the sodium-potassium pump uses the energy in ATP to pump two potassium ions (K^+) into the cell and expel three sodium ions (Na^+).

Why Electrolytes Are Needed for Nerve Conduction and Muscle Contraction The concentration gradient of sodium and potassium across nerve cell membranes is important for the conduction of nerve impulses. An electrical charge, or membrane potential, exists across nerve cell membranes because the number of negative ions just inside the cell membrane is greater than the number outside. This occurs

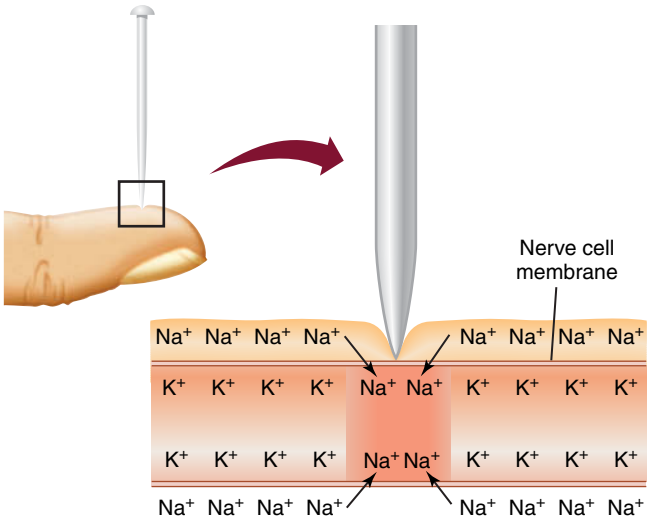


FIGURE 10.15 The role of sodium and potassium in nerve conduction You feel a pinprick because it stimulates nerves beneath the surface of the skin. This stimulation increases the permeability of the nerve cell membrane to sodium, which rushes into the cell (shown here), initiating a nerve impulse.

because the cell membrane allows more positively charged ions to leak out of the cell than to leak into the cell. Nerve impulses are created by a change in the electrical charge across cell membranes. Stimuli, such as touch or the presence of neurotransmitters, increase the cell membrane's permeability to sodium, allowing it to rush into the cell (Figure 10.15). This reverses, or depolarizes, the charge of the cell membrane at that location, and an electrical current is generated. The nerve impulse travels along the nerve cell as an electrical current. Once the nerve impulse passes, the original membrane potential is rapidly restored by another change in cell membrane permeability; then the original distribution of sodium and potassium ions across the cell membrane is restored by the sodium-potassium pump in the cell membrane. A similar mechanism causes the depolarization of the muscle cell membranes, leading to muscle contraction.

How Electrolyte Balance Is Regulated

In northern China, typical daily sodium chloride intake is greater than 13.9 g; in the Kalahari Desert, it is less than 1.7 g; among the Yanomani Indians of Brazil, consumption may be less than 0.06 g.[1] Despite these variations in intake, homeostatic mechanisms ensure that blood levels of sodium do not differ significantly among these groups.

Sodium and Chloride Homeostasis

Sodium and chloride homeostasis is regulated to some extent by the intake of both water and salt. When salt intake is high, thirst is stimulated to increase water intake. When salt intake is very low, a "salt appetite" causes the individual to crave salt. While this salt appetite promotes adequate salt intake, the desire for salt is also a learned preference. For example, the amounts of salt in the U.S. diet are far too high for salt appetite to be activated; the craving that triggers your desire to plunge into a bag of salty chips is due to a learned preference. If you cut back on your salt intake, you will find that your taste buds become more sensitive to the presence of salt, and foods taste saltier.

renin An enzyme produced by the kidneys that converts angiotensinogen to angiotensin I.

angiotensin II A compound that causes blood vessel walls to constrict and stimulates the release of the hormone aldosterone.

Thirst and salt appetite help ensure that appropriate proportions of salt and water are taken in, but the kidneys are the primary regulator of sodium, chloride, and potassium balance in the body. Excretion of these electrolytes in the urine is decreased when intake is low and increased when intake is high. Because water follows sodium by osmosis, the ability of the kidneys to conserve sodium provides a mechanism to conserve body water.

Sodium plays a pivotal role in regulating extracellular fluid volume. When the concentration of sodium in the blood increases, water follows by osmosis, causing an increase in blood volume. Changes in blood volume can change blood pressure. Changes in blood pressure trigger the production and release of proteins and hormones that affect the amount of sodium, and hence water, retained by the kidneys. For example, when blood pressure decreases, the kidneys release the enzyme **renin**, beginning a series of events leading to the production of **angiotensin II**

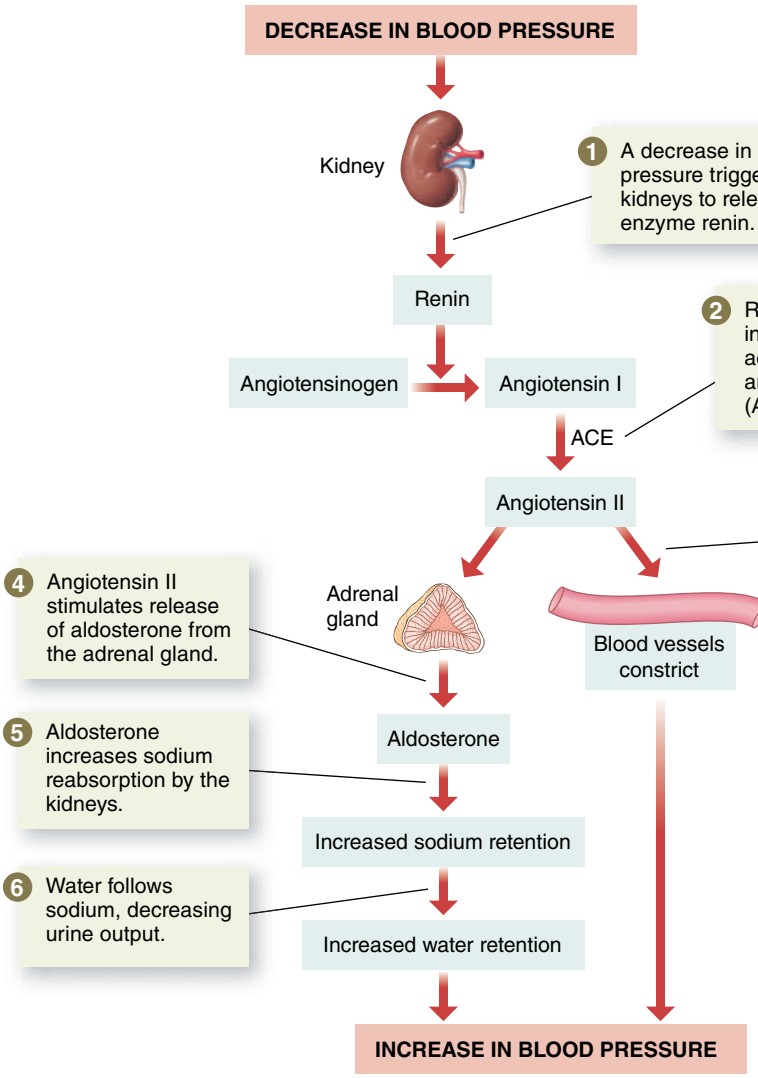


FIGURE 10.16 Regulation of blood pressure
A drop in blood pressure triggers events that cause blood vessels to constrict and the kidneys to retain water. An increase in blood pressure inhibits these events so that blood pressure does not continue to rise.

THINK CRITICALLY

People with high blood pressure are often prescribed drugs called ACE inhibitors. Explain why they lower blood pressure.

(Figure 10.16). Angiotensin II increases blood pressure both by causing the blood vessel walls to constrict and by stimulating the release of the hormone **aldosterone**, which acts on the kidneys to increase sodium (and chloride) reabsorption. Water follows the reabsorbed sodium, helping to maintain blood volume and, consequently, blood pressure. As blood pressure increases, it inhibits the release of renin and aldosterone so that blood pressure does not continue to rise.

aldosterone A hormone that increases sodium reabsorption by the kidney and therefore enhances water retention.

Potassium Homeostasis The amount of potassium in the body is also tightly regulated. If blood levels begin to rise, mechanisms are activated to stimulate the cellular uptake of potassium. This short-term regulation prevents the amount of potassium in the extracellular fluid from getting lethally high. The long-term regulation of potassium balance depends on aldosterone release, which causes the kidneys to excrete potassium and retain sodium. Aldosterone release is stimulated by high blood potassium, low blood sodium, or angiotensin II.

Electrolyte Deficiency

Deficiencies of any of the electrolytes can lead to electrolyte imbalance, which disrupts physiological functions throughout the body, leading to acid–base imbalance, poor appetite, muscle cramps, confusion, apathy, constipation, and, eventually, an irregular heartbeat. The sudden death that can occur in fasting, anorexia nervosa, or starvation may be due to heart failure caused by potassium deficiency.

Sodium, chloride, and potassium depletion can occur when losses are increased due to heavy and persistent sweating, chronic diarrhea or vomiting, or kidney disorders that lead to excessive urinary losses. It is obvious that these situations increase water losses, but the water that is lost carries electrolytes with it. If the electrolytes are not replaced along with the water, electrolyte imbalances can result. For example, if athletes lose a lot of sodium in sweat but replace only the water, they may suffer from hyponatremia (see Chapter 13). Likewise, someone who has lost fluid and electrolytes from diarrhea should replace both. These can be replaced by consuming electrolyte-containing liquids, such as chicken broth or commercial oral rehydration fluids. These are often recommended for young children who have had an extended bout of diarrhea or vomiting.

Medications can also interfere with electrolyte balance. For example, thiazide diuretics, which are used to treat hypertension, cause potassium loss. Generally, potassium supplements are prescribed along with or incorporated into medications that cause potassium loss.

Electrolyte Toxicity

Electrolyte toxicity is rare when water needs are met and kidney function is normal. It is difficult to consume more sodium than the body can handle because we usually drink more water when we consume more sodium. Though rare, elevation of blood sodium can result from massive ingestion of salt, such as may occur from drinking seawater or consuming salt tablets. The most common cause of high blood sodium is dehydration, and the symptoms of high blood sodium are similar to those of dehydration.

It is not possible for healthy people to consume too much potassium from foods. If, however, potassium supplements are consumed in excess or kidney function is compromised, blood levels of potassium can increase and potentially cause death due to an irregular heartbeat. A high oral dose of potassium generally causes vomiting, but if too much potassium enters the blood, it can cause the heart to stop. Table 10.1 provides a summary of the sources, recommended intakes, functions, deficiencies, and toxicities of water, sodium, potassium, and chloride.

TABLE 10.1 A Summary of Water and the Electrolytes

Nutrient	Sources	Recommended intake for adults	Major functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
Water	Drinking water, other beverages, and food	2.7–3.7 L/day[a]	Solvent, reactant, protector, transporter, regulator of temperature and pH	Thirst, dark-colored urine, weakness, poor endurance, confusion, disorientation	Infants; people with fever, vomiting, or diarrhea; elderly individuals; athletes	Confusion, coma, convulsions	ND
Sodium	Table salt, processed foods	<2300 mg; ideally 1500 mg/day[a]	Major positive extracellular ion, nerve transmission, muscle contraction, fluid balance	Muscle cramps, nausea, disorientation, confusion, fluid in tissues	People consuming too much water compared to sodium, those with vomiting or diarrhea or who sweat excessively	High blood pressure in sensitive people	2300 mg/day
Potassium	Fresh fruits and vegetables, legumes, whole grains, milk, meat	4700 mg/day[a] or more	Major positive intracellular ion, nerve transmission, muscle contraction, fluid balance	Irregular heartbeat, fatigue, muscle cramps	People consuming poor diets high in processed foods, people with diarrhea or vomiting, those taking thiazide diuretics	Abnormal heartbeat	ND
Chloride	Table salt, processed foods	<3600 mg/day; ideally 2300 mg/day[a]	Major negative extracellular ion, fluid balance	Unlikely	None	None likely	3600 mg/day

[a]Adequate Intakes (AIs).

Note: UL, Tolerable Upper Intake Level; ND, not determined due to insufficient data.

10.4 Hypertension

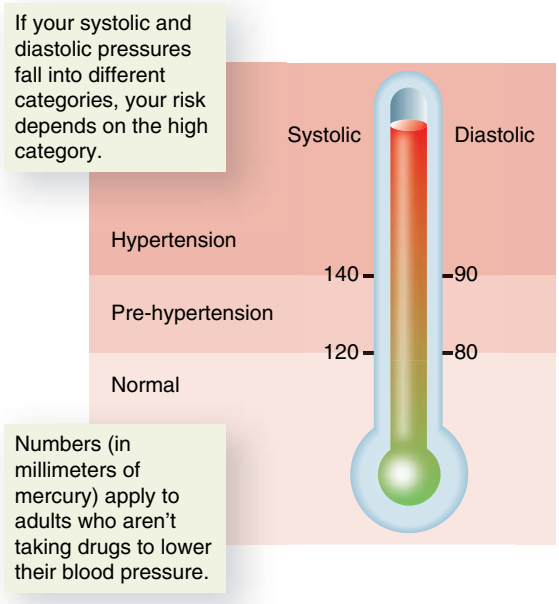
LEARNING OBJECTIVES

- Define *hypertension*, and list its symptoms and consequences.
- Discuss the effect of dietary salt intake on blood pressure.
- Describe the DASH diet and how it affects blood pressure.

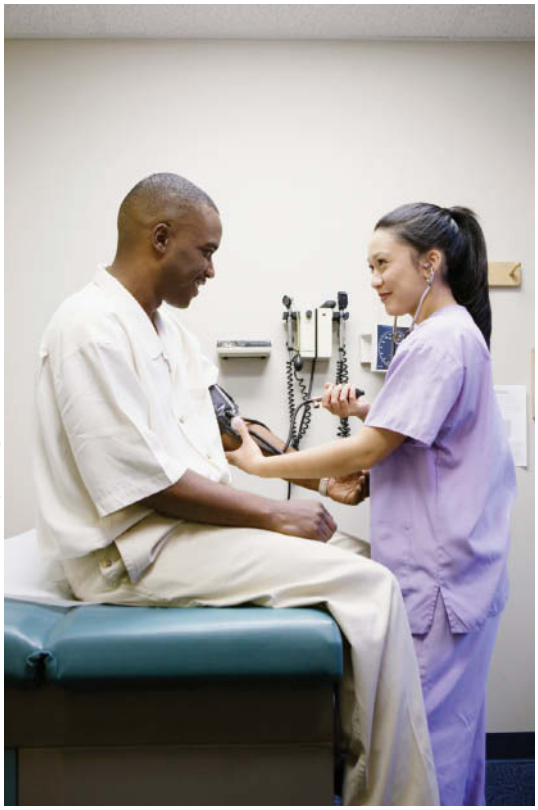
Hypertension, or high blood pressure, has been called the "silent killer" because it has no outward symptoms but can lead to atherosclerosis, heart attack, stroke, kidney disease, and early death. Hypertension is a serious public health concern in the United States: About one in three U.S. adults has hypertension; of these, 17% don't know they have it.[13] Among hypertensive adults, 76% are using medications to control their blood pressure but only 54% have their blood pressure under control.[13]

A certain level of blood pressure is necessary to ensure that blood is delivered to all the body tissues. An optimal blood pressure is less than 120/80 mm Hg. The higher number is systolic pressure, the maximum pressure in the artery, occurring when the heart is contracting. The lower number is diastolic pressure, the minimum pressure in the artery, occurring when the heart is resting between beats. Blood pressures from 120/80 to 139/89 mm Hg are referred to as *prehypertension*. Prehypertension affects 36% of Americans and indicates an increased risk for developing hypertension.[13,14] Blood pressure that is consistently 140/90 mm Hg or greater indicates hypertension (Figure 10.17) (see online Appendix F).[13]

FIGURE 10.17 Assessing blood pressure



A. A healthy blood pressure is less than 120/80 mm Hg. Health risks increase as blood pressure increases above the normal range.



Andersen Ross/Photodisc Red//Getty Images, Inc.

B. Blood pressure should be monitored regularly. It is measured using a blood pressure meter called a sphygmomanometer. It consists of an inflatable cuff that restricts blood flow and a pressure meter. A stethoscope is used to listen to the sounds of blood flow that indicate systolic and diastolic pressures.

What Causes Hypertension?

Hypertension occurs when the pressure of the blood against the arterial wall increases. In most cases we don't know the cause. Hypertension with no obvious external cause is referred to as *essential hypertension*. It is a complex disorder, most likely resulting from disturbances in one or more of the mechanisms that control body fluid and electrolyte balance. High blood pressure that occurs as a result of other disorders is referred to as *secondary hypertension*. For example, if atherosclerosis causes a reduction in blood flow to the kidneys, the kidneys respond by releasing renin. This triggers events that lead to an increase in blood volume and a constriction of blood vessels. This raises blood pressure to the kidneys but also raises blood pressure throughout the body.

Factors That Affect the Risk of Hypertension

The risk of developing high blood pressure is affected by genetics, age, existing disease conditions, and lifestyle factors. A family history of high blood pressure increases your risk of developing this disorder. The genetic basis of hypertension is also illustrated by the fact that it is more common in people of certain ethnic and racial backgrounds. For example, 45% of African American men have high blood pressure compared to 33% of Caucasian men; in African Americans hypertension develops earlier in life and average blood pressure is higher.[13] The higher incidence among African Americans is reflected in their 1.8 times greater rate of death from stroke, 1.5 times greater rate of death from heart disease, and 4.2 times greater rate of hypertension-related kidney failure compared to Caucasians.[13] The risk of hypertension increases in adults as they age. One reason is that as people age the arteries lose their elasticity. Hypertension is generally uncommon in children and adolescents, but the frequency has been increasing, in part due to the increased prevalence of obesity.[13] Obesity, particularly abdominal obesity, increases the risk of hypertension. Excess adipose tissue adds miles of capillaries through which blood must be pumped. Weight loss can prevent or delay the onset of hypertension in individuals who are obese. Diabetes also increases the risk of high blood pressure, as do a lack of physical activity, heavy alcohol consumption, smoking, stress, and a number of dietary factors (**Table 10.2**).[14]

How Diet Affects Blood Pressure

The correlation between sodium and blood pressure is well known.[15] On average, as sodium intake goes up, so does blood pressure, but sodium is not the only nutrient that affects blood pressure. Diets high in potassium, calcium, and magnesium are associated with a lower average blood pressure. Other components of the diet, such as the amount of fiber and the type and amount of fat, may also affect the risk of developing hypertension.

TABLE 10.2 Lifestyle Choices to Keep Blood Pressure in the Normal Range

- Eat plenty of fruits and vegetables—they are naturally low in salt and calories and rich in potassium.
- Reduce sodium intake by limiting processed foods and preparing foods with less salt.
- Aim for a healthy weight—blood pressure increases with increases in body weight and decreases when excess weight is reduced.
- Increase physical activity—it helps lower blood pressure, reduce the risk of other chronic diseases, and manage weight.
- If you drink alcoholic beverages, do so in moderation. Excessive alcohol consumption has been associated with high blood pressure.
- Quit smoking.
- Reduce stress—over time, stress can raise blood pressure and contribute to the development of hypertension.

Sodium Intake and Blood Pressure The relationship between sodium intake and blood pressure was first identified by examining the incidence of hypertension in populations with different average dietary salt intakes. In populations consuming less than 1800 mg of sodium per day, average blood pressure was low and hypertension was rare or absent. In populations consuming more than about 2300 mg of sodium per day, blood pressure increased with sodium intake.[16] More recent intervention trials have examined the effect of different levels of sodium intake on blood pressure. It was found that the lower the amount of sodium in the diet, the lower the blood pressure.[17,18] When compared to an intake of 3300 mg of sodium (a level slightly less than the average amount consumed by Americans), an intake of 2400 mg of sodium reduced blood pressure in those with and without hypertension, and even more significant reductions were seen when sodium intake was reduced to 1500 mg per day. These studies and others are the basis for the current DRIs and Dietary Guidelines recommendations, which are discussed below. Despite the general effect of sodium intake on blood pressure, not everyone who consumes more than the recommended daily amount of sodium will develop hypertension. The degree of salt sensitivity an individual has determines how that person's blood pressure will respond to changes in dietary sodium intake. Individuals with hypertension, diabetes, or chronic kidney disease, as well as older individuals and African Americans, tend to be more sensitive to sodium intake.[1]

Dietary Patterns and Blood Pressure Diets high in sodium increase the risk of high blood pressure and diets high in the minerals potassium, magnesium, and calcium are associated with lower blood pressure.[19] Despite these data, studies that have explored the impact of individual nutrients on blood pressure are often inconclusive. This may be because the impact of each individual nutrient is small and other dietary components are also important in blood pressure regulation. This prompted researchers to begin exploring the impact of the total dietary pattern on blood pressure and overall health.

The first intervention trial to look at the effect of a dietary pattern high in potassium, calcium, and magnesium on blood pressure was the DASH trial, which stands for Dietary Approaches to Stop Hypertension (see **Science Applied: A DASH to Heart Health**).[20] In this trial, the amount of dietary sodium was kept constant and different dietary patterns were compared in terms of their effect on blood pressure. The greatest reduction in blood pressure was found with a dietary pattern that is high in fruits and vegetables and includes low-fat dairy products and lean meat, fish, and poultry. This pattern provides plenty of fiber, potassium, magnesium, and calcium; is low in total fat and saturated fat; and is lower in sodium than the typical American diet. Consuming a diet that follows the DASH pattern lowers blood pressure in individuals with elevated blood pressure even when sodium levels are not severely restricted. Reductions in blood pressure are greater when sodium intake is lower.[18] The results of the DASH trial demonstrate that changing the dietary pattern can lower blood pressure.

10.5 Healthy Electrolyte Intakes

LEARNING OBJECTIVES

- Discuss the rationale for lowering sodium intake.
- Plan a DASH diet that meets your calorie needs.

The typical American diet is high in processed foods and low in fruits and vegetables and as a result is high in sodium and low in potassium. To meet recommendations for a healthy diet, most people in the United States need to change their dietary pattern to reduce their sodium intake and increase their potassium intake.[15]

SCIENCE APPLIED

A DASH to Heart Health

For over 30 years, the National Heart, Lung, and Blood Institute (NHLBI) of the National Institutes of Health (NIH) made recommendations for the treatment of high blood pressure through modifications of individual dietary components such as sodium and other minerals as well as fat, cholesterol, fiber, and protein. But the data supporting some of these nutrient-intake recommendations were often conflicting and equivocal. This led the NHLBI to pursue a clinical trial that would evaluate the effects of dietary patterns rather than individual dietary components on blood pressure.[21] The result was the DASH (Dietary Approaches to Stop Hypertension) trial, which provided conclusive evidence that diet does affect blood pressure.[20]

THE SCIENCE

Designing the DASH trial presented several challenges. The study required large numbers of subjects to consume a specific diet for a fairly long period. To accrue enough subjects, the study needed to be run simultaneously from several different study centers. Subjects' diets had to be standardized across these centers.[20] Controlling dietary intake also presented challenges because the subjects had to consume one meal a day, five days a week at the research study centers; the remaining meals were prepared by the research centers and sent home with the subjects to be consumed at home. To control for extra intake, subjects were also required to keep a daily diary of any nonstudy items consumed.

The DASH study population included 459 adults with slightly elevated blood pressure who were not taking blood pressure medications. All study subjects consumed the same control diet for the first three weeks of the study, and their blood pressure was monitored. Subjects were then randomly assigned to one of three dietary groups for eight weeks. During this intervention period, blood pressure was measured by individuals who did not know to which dietary groups the participants had been assigned.

The study diets included a "control" diet, a "fruits and vegetables" diet, and a "combination" diet. Each diet provided about 3000 mg of sodium—slightly lower than the typical U.S. intake—and enough calories to maintain body weight. The "control" diet was a typical American dietary pattern—low in fiber and high in fat and saturated fat. It matched the average U.S. nutrient intake except for potassium, magnesium, and calcium, which were set below average. The "fruits and vegetables" diet increased servings of fruits and vegetables and decreased sweets but was otherwise similar to the control diet. This diet was higher in fiber than the control, and the potassium and magnesium were above the typical American intake. The "combination" diet increased fruits, vegetables, and low-fat dairy products and reduced red meat, sweets, and sugar-sweetened drinks; it was higher in potassium, calcium, magnesium, and fiber than the control diet and was lower in total fat, saturated fat, and cholesterol.

After only two weeks, participants consuming the "fruits and vegetables" diet had a blood pressure reduction of 2.8 mm Hg systolic and 1.1 mm Hg diastolic. Those consuming the "combination" diet, which is now known as the DASH diet

Recommended Sodium, Chloride, and Potassium Intakes

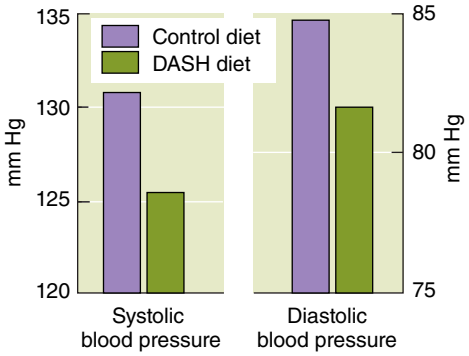
The typical daily intake of sodium in the United States is over 3400 mg.[15] The AI for sodium for adults ages 19 to 50 years is 1500 mg/day.[1] This amount ensures an adequate intake of other nutrients and accounts for sodium losses in sweat. The UL for sodium is 2300 mg, based on the increase in blood pressure seen with higher sodium intakes. This is similar to the Dietary Guidelines recommendation of a daily sodium intake of less than 2300 mg/day.[15] For people ages 51 or older and those of any age who are African American or have hypertension, diabetes, or kidney disease, sodium intake should be reduced to 1500 mg/day, which is equivalent to the AI for sodium for adults ages 19 to 50.

The AI for chloride is 2300 mg/day; the UL for chloride is 3600 mg/day.[1] The AI for sodium and chloride is equivalent to 3.8 g of salt per day, which is less than half of the typical daily intake of over 8.5 g of salt, or about 1.5 tsp/day.[22] The Daily Value for sodium used on food labels is no more than 2400 mg of sodium per day (6 g salt).

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)



Consuming a DASH diet lowered both systolic and diastolic blood pressure compared to the control diet (typical American diet) even though both dietary groups consumed 3000 mg of sodium per day. Reducing dietary sodium intake causes a further reduction in blood pressure.

or DASH Eating Plan, had a reduction in blood pressure of 5.5 mm Hg systolic and 3 mm Hg diastolic compared with the control group (see graph).[20] If the U.S. population were to adopt the DASH diet, it is estimated that the incidence of coronary heart disease would be reduced by 15% and stroke by 27%.

A second DASH study, called DASH-Sodium, compared the effect of different levels of sodium intake on blood pressure in subjects consuming either the DASH Eating Plan or a control diet (typical American diet).[18] Lowering the sodium lowered blood pressure in subjects consuming both the DASH and control diets. Those consuming the DASH diet and the lowest sodium level, 1500 mg/day, had the greatest reduction in blood pressure—an effect equal to or greater than what would be expected from treatment with a single antihypertensive medication.

THE APPLICATION

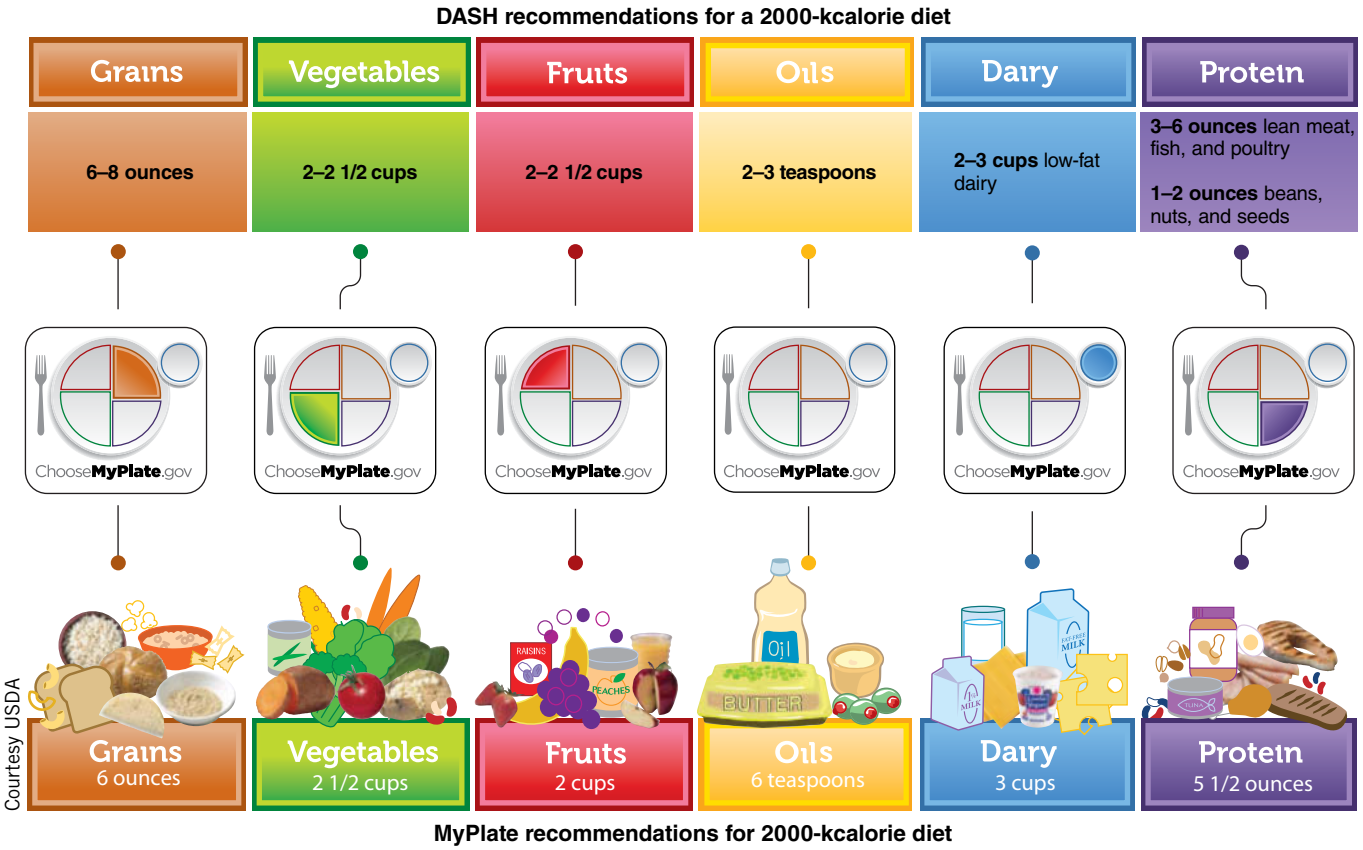
When many dietary factors are modified simultaneously, as in the DASH trial, it is impossible to determine which ones cause the effects seen. Therefore, the DASH trial taught scientists less about the physiology of hypertension than do studies that look at individual factors, but it provided more information about what people should eat to prevent or reduce hypertension. It shifted the focus of diet and disease prevention from individual nutrients or foods to dietary patterns. There is no single dietary prescription for health. Healthy dietary patterns can include a multitude of food choices and combinations to satisfy differences in personal tastes and preferences based on culture, ethnicity, and tradition. The DASH diet and other healthy eating patterns help reduce the risk of not only hypertension but also a host of other nutrition-related chronic diseases.

THINK CRITICALLY: Why do you think the DASH diet had a greater effect on blood pressure than just lowering sodium intake?

The AI for potassium is set at 4700 mg/day, a level that will lower blood pressure and reduce the adverse effects of sodium on blood pressure. Few Americans currently consume enough potassium to meet this recommendation. The Dietary Guidelines recommend that Americans increase their intake of foods that are rich in potassium and proposed changes to food labels have identified potassium as a nutrient at risk in the American diet (see Chapter 2).[15] No UL has been set for potassium because potassium intake from foods is not a risk in healthy people with normal kidney function.

There is no evidence that sodium and chloride requirements differ during pregnancy, so pregnant women are advised to follow the recommendations for the general population (see Chapter 14).[1] At one time, a dietary salt restriction was common during pregnancy to prevent a spectrum of conditions involving high blood pressure known as hypertensive disorders of pregnancy. The cause of these disorders is not known, but salt restriction is no longer recommended. Potassium recommendations are not increased during pregnancy, but during lactation the AI is higher to account for the potassium lost in milk. In infants, sodium, chloride,

FIGURE 10.18 Dietary patterns to lower blood pressure



A. The recommendations of the DASH Eating Plan (upper portion of the figure) are similar to those of MyPlate (lower portion). Both recommend eating plenty of fruits and vegetables; choosing whole grains; having beans, nuts, seeds, and fish more often; and choosing lean meats and low-fat dairy products.

and potassium needs are estimated from the amount consumed in human milk, which contains more chloride than sodium. This same chloride-to-sodium ratio has been recommended for infant formulas.

Choosing a Dietary Pattern to Lower Blood Pressure

The typical American diet contains over 3400 mg of sodium—an amount above the UL—and only about 2000 to 3000 mg of potassium—well below the recommendation of 4700 mg/day. This discrepancy between intake and recommendations exists because most Americans consume a diet high in processed foods and low in fruits and vegetables. Fruits and vegetables are the best sources of potassium per calorie. When diets are high in fruits and vegetables, potassium intakes of 8000 to 11,000 mg/day are not uncommon.[1] Choosing a dietary pattern that will increase potassium and reduce sodium to meet recommendations will help to control blood pressure.

MyPlate and the DASH Eating Plan recommend dietary patterns that are high in fruits and vegetables and whole grains, and include lean protein sources and low-fat dairy products (Figure 10.18). These dietary patterns, which are high in potassium, calcium, magnesium, and fiber and low in sodium, have been shown to lower blood pressure (see **Critical Thinking: DASHing a Diet**). The Mediterranean diet and vegetarian diets are rich in similar types of foods and have also have been shown to help lower blood pressure.[22, 23] All of these

DASH Eating Plan at Different Energy Levels

Food group	Serving sizes	Daily servings per kilocalorie level			
		1600	2000	2600	3100
Grains[a]	1 slice bread, 1 oz dry cereal, ½ cup cooked rice, pasta, or cereal	6	6–8	10–11	12–13
Vegetables	1 cup raw leafy vegetables, ½ cup raw or cooked vegetables, or vegetable juice	3–4	4–5	5–6	6
Fruits	1 medium fruit, ¼ cup dried fruit, ½ cup fresh, frozen, or canned fruit, or fruit juice	4	4–5	5–6	6
Low-fat dairy	8 oz milk,1 cup yogurt, 1½ oz cheese	2–3	2–3	3	3–4
Lean meats, fish, poultry	1 oz cooked meat, poultry, or fish	3–4 or less	6 or less	6 or less	6–9
Beans, nuts, and seeds	⅓ cup or 1½ oz nuts, 2 T or ½ oz seeds, ½ cup cooked dry beans or peas	3–4/ week	4–5/ week	1/day	1/day
Fat and oils[b]	1 tsp soft margarine, 1 T low-fat mayonnaise, 1 T light salad dressing, 1 tsp vegetable oil	2	2–3	3	4
Sweets and added sugar	1 T sugar, 1 T jelly or jam, ½ cup sorbet, 8 oz lemonade	≤3/ week	≤5/ week	≤2/ week	≤2/ week

[a]Whole grains are recommended for most servings to meet fiber recommendations.

[b]Fat content changes the number of servings for fats and oils. 1 T regular salad dressing equals one serving; 1 T low-fat dressing equals ½ serving; 1 T of fat-free dressing equals 0 servings.

B. The table provides the number of servings from each of the DASH Eating Plan food groups for four different energy levels.

Andy Washnik

C. A diet that is high in fruits and vegetables, which are good sources of potassium, magnesium, and fiber, reduces blood pressure compared to a similar diet containing fewer fruits and vegetables. The amounts in the measuring cups shown here, about 2 cups of fruits and 2½ cups of vegetables, represent the amount recommended for a 2000-kcal diet.

healthy dietary patterns may also reduce cancer risk, prevent osteoporosis, and protect against diabetes and heart disease.[14]

Even diets high in fruits and vegetables can provide more than the recommended amount of sodium. The amount of sodium in the diet can be reduced by limiting intake of highly processed foods. Despite the focus of recommendations on reducing sodium intake, the amount of sodium added to processed foods has not changed much since 2005.[24] The Nutrition Facts panel and Nutrient content claims on food labels can be helpful in selecting lower-sodium products (see **Off the Label: Look for Less Sodium and More Potassium** and Table 10.3).

Foods with less salt may taste bland at first, but this preference for salt is learned. Therefore, it is suggested that people try to lower sodium intake slowly.[15] Reducing sodium intake by at least 1000 mg/day is recommended even if sodium intake cannot be reduced as low as the 1500-mg recommendation. After consuming lower-salt foods for a period of time, the desire for salt decreases. Adding other flavorings such as onions, garlic, lemon juice, vinegar, black pepper, parsley, and other herbs to food may also help satisfy your taste for flavorful food without adding sodium. **How to Choose: A Diet with Less Sodium** provides some tips for reducing sodium intake.

CRITICAL THINKING

DASHing a Diet

iStockphoto

Rashamel has a family history of hypertension. He exercises for about 30 minutes on most days of the week, doesn't smoke, watches his weight, and doesn't add salt to his food. Despite these efforts, at his recent physical his blood pressure was 138/87 mm Hg, which is in the prehypertension category. Rashamel's doctor suggests he see a dietitian to help him change his diet to follow the DASH Eating Plan. His current diet is shown here.

▼

Compare Rashamel's current sodium intake to the AI.

CURRENT DIET	SERVING	ENERGY (kcal)	SODIUM (mg)
Breakfast			
Orange juice	¾ cup	84	2
1% low-fat milk	1 cup	102	107
Wheaties w/1 tsp sugar	1 cup	149	253
Whole-wheat bread w/jelly	1 slice	99	122
Margarine	1 tsp	33	44
Lunch			
Tuna salad	¾ cup	288	618
Whole-wheat bread	2 slices	124	236
Chips	1 oz	150	136
Cola	12 oz can	136	15
Dinner			
Baked chicken	3 oz	140	63
Teriyaki sauce	1 T	30	1220
Fried rice	1 cup	333	822
Salad	1 cup	22	36
Light salad dressing	1 T	30	160
Dinner roll	1	78	138
Margarine	2 tsp	66	87
Cantaloupe	½ cup	27	13
Iced tea (sweetened)	12 oz	90	4
Snacks			
Cookies	2 large	156	110
Dried apricots	5	84	4
Milky Way candy bar	1	260	95
Cola	12 oz can	136	15

▼

Which five foods provide the most sodium?

CRITICAL THINKING QUESTIONS

- **Suggest some changes to Rashamel's diet that would reduce his sodium intake to 2300 mg or less.**
- **Suggest foods that Rashamel could add to his diet to meet the recommendations of the DASH Eating Plan for a 2600-kcal diet (see Figure 10.18B).**
- **Adding foods to meet the DASH recommendations will increase the calories in Rashamel's diet. What foods could he eliminate to still meet the DASH recommendations but not exceed his calorie needs?**

iProfile Use iProfile to find out how much sodium is provided by your favorite snack foods.

© iStockphoto

OFF THE LABEL

Look for Less Sodium and More Potassium

Most of the sodium in the American diet comes from processed foods. Sodium chloride is the most common form in which sodium is added to foods; other sodium-containing ingredients include sodium hydroxide, sodium salts such as baking soda and baking powder, and monosodium glutamate (MSG).

Food labels list the sodium-containing ingredients in the ingredient list, and the Nutrition Facts panel gives the total amount of sodium in milligrams. To help you assess how the amount of sodium fits into the recommendations for a healthy diet, the sodium content of a serving is given as a percentage of the Daily Value, which is 2400 mg. For example, the current Nutrition Facts label shown on the left indicates that a serving of this spaghetti sauce contains 250 mg of sodium, or 10% of the Daily Value. In general, a food with 5% or less of the Daily Value is low in sodium, and one with 20% or more is high in sodium. Potassium information is voluntary on the current label. Because potassium is a nutrient of concern for underconsumption in the American diet, proposed changes to the Nutrition Facts label, shown on the right, would require this information to be listed along with the amounts of calcium, iron, and vitamin D.

Food labels also include descriptors relating to salt or sodium content, such as the "Light in Sodium" claim made on this label (see Table 10.3). Additionally, a health claim that diets low in sodium may reduce the risk of high blood pressure can appear on foods that meet the definition of a low-sodium food and provide less than 20% of the Daily Value for fat, saturated fat, and cholesterol per serving. Some medications, such as pain relievers, antacids, and cough medications, can also contribute a significant amount of sodium. Drug facts labels on over-the-counter medications can help identify those that contain significant amounts of sodium.

Current food label

Nutrition Facts

Serving Size 1/2 cup (125g)
Servings Per Container about 3½

Amount Per Serving	
Calories 50	Calories from Fat 10
	%Daily Value**
Total Fat 1g	**2%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 250mg	**10%**
Potassium 530mg	**15%**
Total Carbohydrate 9g	**3%**
Dietary Fiber 1g	**4%**
Sugars 7g	
Protein 2g	

Vitamin A 10% • Vitamin C 25%
Calcium 2% • Iron 10%

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

	Calories:	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Potassium		3,500mg	3,500mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Light Spaghetti Sauce, 250 milligrams (mg) per serving
Regular Spaghetti Sauce, 500 mg per serving

Proposed food label

Potassium information is currently voluntary. Proposed label changes would require it on all labels.

Nutrition Facts

3½ Servings per container
Servings size 1/2 cup (125g)

Amount Per 1/2 cup
Calories 50

% DV*	
2%	**Total Fat** 1g
0%	**Saturated Fat** 0g
	***Trans* Fat** 0g
0%	**Cholesterol** 0mg
10%	**Sodium** 250mg
3%	**Total Carbs** 9g
4%	**Dietary Fiber** 1g
	Sugars 7g
	Added Sugars 5g
	Protein 2g
0%	**Vitamin D** 0mcg
2%	**Calcium** 20mg
10%	**Iron** 2mg
15%	**Potassium** 530mg

* Footnote on Daily Values (DV) and calories reference to be inserted here.

THINK CRITICALLY: If instead of a serving of this spaghetti sauce, which is light in sodium, you ate a serving of regular spaghetti sauce, how much more sodium would you be consuming?

TABLE 10.3 Salt and Sodium on Food Labels

Sodium-free	Contains less than 5 mg of sodium per serving.
Salt-free	Must meet criterion for "sodium-free."
Very low sodium	Contains 35 mg or less of sodium per serving.
Low sodium	Contains 140 mg or less of sodium per serving.
Reduced or less sodium	Contains at least 25% less sodium per serving than a reference food.
Light in sodium	Contains at least 50% less sodium per serving than the average reference amount for the same food with no sodium reduction.
No salt added, without added salt, and unsalted	No salt is added during processing, and the food it resembles and for which it substitutes is normally processed with salt. (If the food is not "sodium-free," the statement "not a sodium-free food" or "not for control of sodium in the diet" must appear on the same panel as the Nutrition Facts panel.)
Lightly salted	Contains at least 50% less sodium per serving than a reference food. (If the food is not "low in sodium," the statement "not a low-sodium food" must appear on the same panel as the Nutrition Facts panel.)
Low-sodium meal	Contains 140 mg or less sodium per 100 g.

HOW TO CHOOSE A Diet with Less Sodium

When shopping

- Check the labels to select foods low in sodium.
- Skip the chips and replace them with unsalted nuts.
- Choose more fresh and frozen foods—they have less sodium than canned foods.

When cooking

- Do not add salt to the water when cooking rice, pasta, and cereals.
- Flavor foods with ingredients such as lemon juice, onion or garlic powder (not garlic salt), pepper, curry, dill, basil, oregano, or thyme rather than salt.

When eating

- Limit use of salt at the table.
- Replace ham, bologna, and corned beef, with roasted turkey, chicken, or beef.
- Cut down on cheese, especially processed cheeses.
- Watch what you add—soy sauce, barbecue sauce, ketchup, and mustard are high in sodium.

When eating out

- Choose foods without sauces, or ask for sauces to be served on the side.
- Ask that food be prepared without added salt.
- Limit your intake of fast food—it is usually very high in salt.

OUTCOME

David Tenenbaum/IDAP/Wide World Photos

Despite her ailing appearance, Gabriele Andersen-Scheiss recovered rapidly. Her dehydration was caused by a combination of large fluid losses, inadequate fluid intake, and the fact that she was not well acclimatized to the southern California heat. In such hot conditions, Andersen-Scheiss was not able to replace her fluid losses even with frequent drinks at water stations, so the amount of water in her body began to decline. Her blood volume decreased, and sufficient oxygen and nutrients could not be delivered to her exercising muscles. By the time she entered the stadium for her final lap, the lack of blood to her limbs had caused them to become numb. She observed, "I knew what I wanted to do, but my muscles wouldn't respond anymore." **Her wobbly struggle to finish the women's Olympic marathon in 1984 is a vivid example of what happens when dehydration disrupts the balance of body fluids and electrolytes.**

SUMMARY

10.1 Water: The Internal Sea

- Water is an essential nutrient that provides many functions in the body. The polar structure of water allows it to act as a solvent for the molecules and chemical reactions involved in metabolism. Water helps to transport other nutrients and waste products within the body and to excrete wastes from the body. It also helps to protect the body, regulate body temperature, and lubricate areas such as the eyes and the joints.
- The adult human body is about 60% water by weight. Body water is distributed between intracellular and extracellular compartments. The amount in each compartment depends largely on the concentration of solutes. Since water will diffuse by osmosis from a compartment with a lower concentration of solutes to one with a higher concentration, changes in the concentration of electrolytes and other solutes in each compartment cause changes in the distribution of water.

10.2 Water Balance

- Water cannot be stored, so intake must balance losses to maintain homeostasis. We consume water both in liquids and in solid foods. Fluid intake is stimulated by the sensation of thirst, which occurs in response to a decrease in blood volume and an increase in the concentration of solutes.
- Water is lost from the body in urine and feces, through evaporation from the skin and lungs, and in sweat. The kidney is the primary regulator of water output. If water intake is low, antidiuretic hormone will cause the kidney to conserve water. If water intake is high, more water will be excreted in the urine.
- Dehydration can occur if water intake is too low or output is excessive. Mild dehydration can cause headache, fatigue, loss of appetite, dry eyes and mouth, and dark-colored urine. Severe dehydration can be fatal.
- Water intoxication is not as common as dehydration. It causes hyponatremia, which can result in abnormal fluid accumulation in body tissues.
- The recommended intake of water is 2.7 L/day for adult women and 3.7 L/day for adult men; needs vary depending on environmental conditions and activity level.

10.3 Electrolytes: Salts of the Internal Sea

- The U.S. diet is abundant in sodium and chloride from processed foods and table salt but generally low in potassium, which is high in unprocessed foods such as fresh fruits and vegetables.
- The minerals sodium, chloride, and potassium are important electrolytes in the maintenance of fluid balance and the formation of membrane potentials essential for nerve transmission and muscle contraction.
- Electrolyte and fluid homeostasis is regulated primarily by the kidneys. A decrease in blood pressure or blood volume signals the release of the enzyme renin, which helps form angiotensin II. Angiotensin II causes blood vessels to constrict and the hormone aldosterone to be released. Aldosterone causes the kidneys to reabsorb sodium and hence water, thereby preventing any further loss in blood volume. Failure of these regulatory mechanisms may be a cause of hypertension.
- Low levels of sodium, chloride, and potassium can occur when water and electrolyte losses are increased due to excessive sweating, chronic diarrhea or vomiting, or kidney disorders. High blood sodium most commonly results from dehydration.

10.4 Hypertension

- A healthy blood pressure is less than 120/80 mm Hg. Blood pressure from 120/80 to 139/89 mm Hg is referred to as prehypertension, and blood pressure that is consistently 140/90 mm Hg or greater indicates hypertension. Hypertension affects about a third of adults in the United States. Essential hypertension has no obvious external cause.
- The risk of developing high blood pressure is increased by a family history of hypertension, aging, obesity, diabetes, and lifestyle factors such as a lack of physical activity, heavy alcohol consumption, smoking, stress, and a poor diet.
- Diets high in sodium and low in potassium, magnesium, and calcium are associated with an increased risk of hypertension. The DASH diet—a dietary pattern moderate in sodium; high in potassium, magnesium, calcium, and fiber; and low in fat, saturated fat, and cholesterol—lowers blood pressure. Blood pressure management also requires maintenance of a healthy weight, an active lifestyle, and a limit on alcohol consumption.

10.5 Healthy Electrolyte Intakes

- Recommendations for health suggest that we increase our intake of potassium and consume less sodium. The recommended salt intake is 3.8 g/day for adults ages 19 to 50. Because salt is 40% sodium and 60% chloride by weight, this represents an AI of 1500 mg of sodium and 2300 mg of chloride. The UL for sodium, which is based on the increase in blood pressure seen with higher sodium intakes, is only 2300 mg/day. The AI for potassium is 4700 mg/day. Typical potassium intake is less than 3000 mg/day, so underconsumption is a concern. No UL has been set for potassium.
- Public health recommendations including the Dietary Guidelines suggest that Americans consume a dietary pattern that is high in fruits, vegetables, whole grains, legumes, nuts, and seeds and provides low-fat dairy products and lean meat, fish, and poultry. This dietary pattern, which can be achieved by following the recommendations of the DASH Eating Plan or MyPlate, contains less sodium and more potassium than the typical American diet.

CHAPTER OUTLINE

11.1 What Are Minerals?
- Minerals in Our Diet
- Understanding Mineral Needs

11.2 Minerals, Osteoporosis, and Bone Health
- Bone Structure, Formation, and Breakdown
- Osteoporosis
- How to Prevent and Treat Osteoporosis

11.3 Calcium (Ca)
- Calcium in the Diet
- Calcium in the Digestive Tract
- How Calcium Functions in the Body
- Calcium Deficiency
- Recommended Calcium Intake
- Meeting Calcium Needs
- Excessive Calcium

11.4 Phosphorus (P)
- Phosphorus in the Diet
- Phosphorus in the Digestive Tract
- How Phosphorus Functions in the Body
- Phosphorus Deficiency
- Recommended Phosphorus Intake
- Excessive Phosphorus

11.5 Magnesium (Mg)
- Magnesium in the Diet
- Magnesium in the Digestive Tract
- How Magnesium Functions in the Body
- Magnesium Deficiency
- Recommended Magnesium Intake
- Magnesium Toxicity and Supplements

11.6 Sulfur (S)

(©iStockphoto)

PhotoDisc, Inc./Getty Images

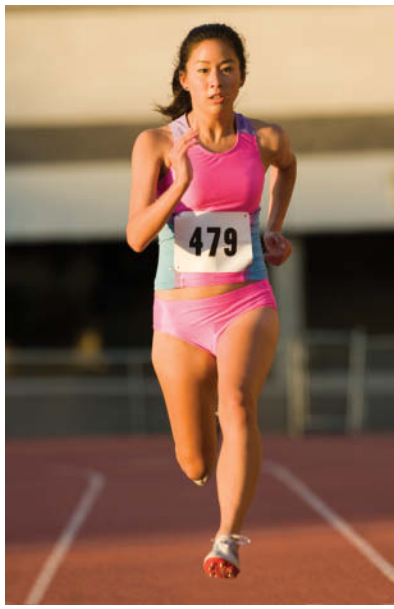
Major Minerals and Bone Health

11

CASE STUDY

Mika began to feel a knife-like pain in the top of her left foot. She tried to keep running, but the pain continued. Frustrated, she limped back to see the trainer. Mika is a 22-year-old college student who currently runs about 40 miles each week on the paths around town. She has been running track since she was a freshman in high school. During her junior year in college, she suffered a stress fracture in her right foot. Now, as a senior, she fears she has a second stress fracture in the left foot.

An evaluation by a physician and some diagnostic tests confirm that Mika has a new stress fracture. In addition to treatment for the fracture, the doctor recommends she have a full medical evaluation. Mika is 5 feet 3 inches tall and weighs 102 lb (BMI = 18.1 kg/m^2). She has lost about 5 lb since the start of her spring training. Her body fat is currently low, at 17%. A medical history reveals that she has not menstruated in almost a year. A diet history discloses that she is lactose intolerant, so doesn't consume much dairy, and that she restricts her overall intake to keep her weight low to improve her running performance. A bone scan shows that Mika has low bone mass in her hips and spine and that her overall bone density is similar to that of a woman in her 60s. Mika is shocked. How could a healthy young woman who gets plenty of outdoor exercise have such low bone density? **What can she do to improve her bone health and prevent future fractures?**



Blend Images/Getty Images, Inc.

11.1 What Are Minerals?

LEARNING OBJECTIVES

- Define *mineral* in terms of nutrition.
- Describe how interactions among minerals and other dietary components affect mineral bioavailability.

mineral In nutrition, an element needed by the body in small amounts for structure and to regulate chemical reactions and body processes.

Minerals are inorganic elements needed by the body as structural components and regulators of body processes. Minerals may combine with other elements in the body, but they retain their chemical identity. Unlike vitamins, they are not destroyed by heat, oxygen, or acid. The ash that remains after a food is combusted in a bomb calorimeter contains the minerals that were present in that food.

Humans need to consume more than 20 minerals to stay healthy. Some of these make up a significant portion of our body weight; others are found in minute quantities. If a mineral is needed in the diet in amounts greater than 100 mg/day (an amount equivalent in weight to about two drops of water) or is present in the body in amounts greater than 0.01% of body weight, the mineral is considered a **major mineral**. The major minerals include the electrolytes sodium, chloride, and potassium, which were discussed in Chapter 10, and calcium, phosphorus, magnesium, and sulfur, which are discussed in this chapter. Minerals that are needed in the diet in an amount of 100 mg or less per day or are present in the body in an amount of 0.01% or less of body weight are referred to as **trace minerals,** or **trace elements** (Figure 11.1). The trace minerals include iron, copper, zinc, selenium, iodine, chromium, fluoride, manganese, molybdenum, and others and are discussed in Chapter 12. Just because we need more of the major minerals than of the trace minerals doesn't mean that one group is more important than the other. A deficiency of a trace mineral is just as damaging to health as a deficiency of a major mineral.

major mineral A mineral needed in the diet in an amount greater than 100 mg/day or present in the body in an amount greater than 0.01% of body weight.

trace mineral or **trace element** A mineral required in the diet in an amount of 100 mg or less per day or present in the body in an amount of 0.01% of body weight or less.

Minerals in Our Diet

Minerals in our diet come from both plant and animal sources (Figure 11.2). Most foods naturally contain minerals, and some foods provide minerals that are added intentionally by

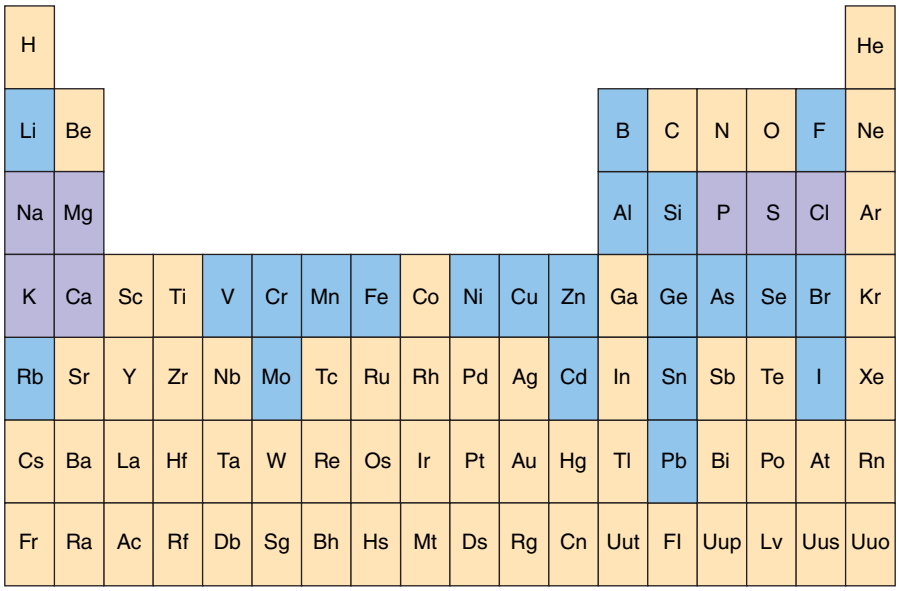


FIGURE 11.1 Major and trace minerals in the periodic table
The major minerals, highlighted in purple, and the trace minerals, in blue, are the same elements found in the periodic table. Although the highlighted elements are essential nutrients, not all the elements in the periodic table are needed by the body.

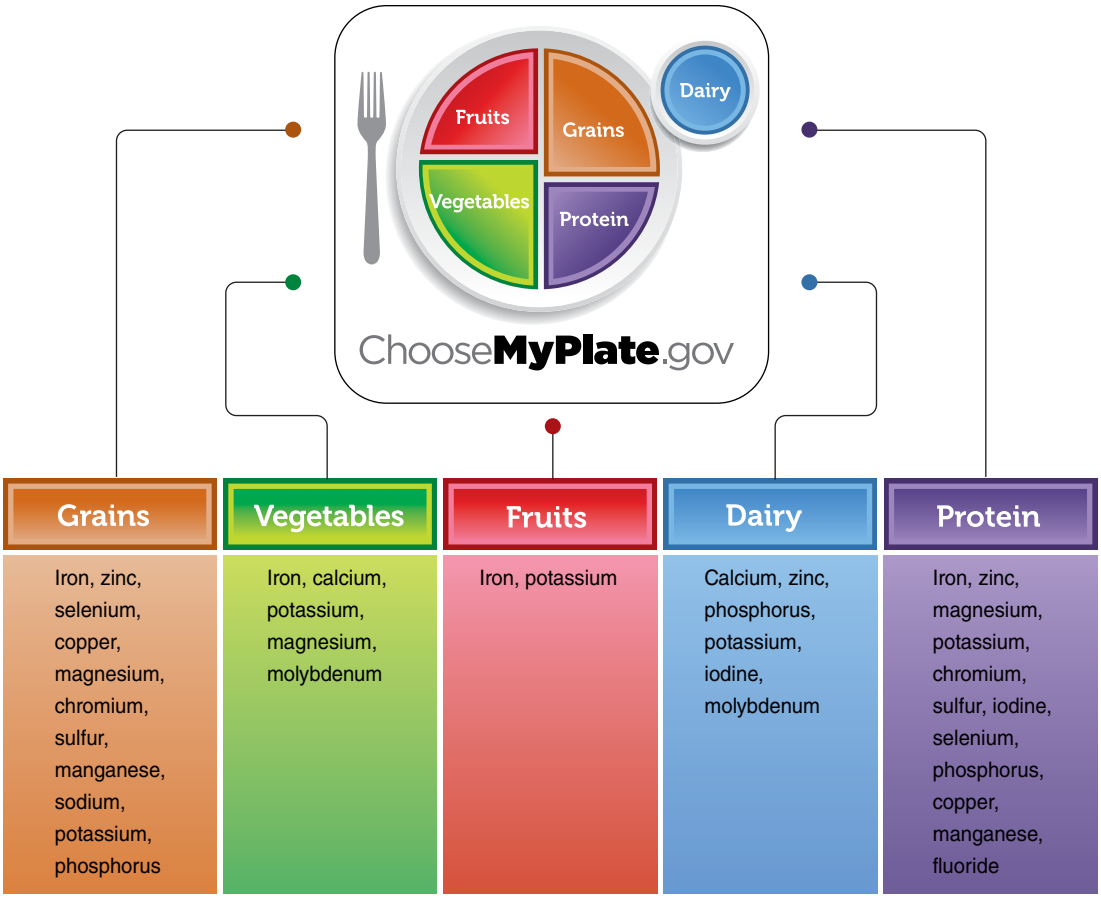


FIGURE 11.2 Minerals in MyPlate food groups
Minerals are found in all the MyPlate food groups; some groups are particularly good sources of specific minerals. Eating a variety of foods, including fresh fruits, vegetables, nuts, legumes, whole grains and cereals, milk, seafood, and lean meats, can maximize your diet's mineral content.

fortification or accidentally through contamination. Dietary supplements are also a source of minerals.

Natural Food Sources of Minerals Some minerals naturally found in foods are present as functional components of the plant or animal and are therefore present in consistent amounts. For instance, the iron content of beef is predictable because iron is part of the muscle protein that gives beef its red color. Magnesium is a component of chlorophyll, so it is found in consistent amounts in leafy greens. The concentrations of other minerals may vary depending on the mineral concentration in the soil and water at the food's source. For example, plants grown in an area where the soil is high in selenium are higher in selenium than plants grown in other areas. In developed countries, modern transportation systems make available foods produced in many locations. This increased variety reduces the risk of getting too much or too little of those minerals that vary in concentration depending on where the food is produced. Individual trace-element deficiencies and excesses are more likely to occur in countries where the diet consists predominantly of locally grown foods.

How Processing Affects the Minerals in Food Food processing and refining can affect the mineral content of foods. Processing does not destroy minerals, but it can still cause losses. For example, when vegetables are cooked, the cells are broken down and potassium is lost in the cooking water. When the skins of fruits and vegetables or the bran and germ of grains are detached, magnesium, iron, selenium, zinc, and copper are lost. Processing also adds minerals to foods. Sodium is frequently added for flavor or as a preservative. The

enrichment of grains has been adding iron to our breads, baked goods, and rice since the 1940s, and today many breakfast cereals, breads, and juices are fortified with calcium. Some minerals enter the food supply inadvertently through contamination. For example, the iodine content of dairy products is increased by contamination from the cleaning solutions used on milking machines.

Dietary Supplements Supplements are also a source of minerals in the modern diet. Some, such as iron, are recommended for certain groups to meet their needs. Others, like chromium, zinc, and selenium, are taken in the hope that they will enhance athletic performance, stimulate immune function, or reduce cancer risk. Although supplements can help people meet the need for specific minerals, eating a variety of foods is the best way to meet mineral needs. Minerals in food are present in amounts that are not toxic, whereas high doses of minerals from supplements can be toxic, and even supplemental amounts that are not toxic can interfere with the absorption and utilization of other minerals, potentially creating mineral imbalances that can be detrimental to health.

Understanding Mineral Needs

To maintain health, the overall diet must contain enough of each of the minerals in the correct proportions. The wrong amounts or combinations can cause deficiency or toxicity. For some minerals, symptoms of a deficient intake occur rapidly and impact short-term health. For example, only a few months of deficient iron intake can cause lethargy and fatigue. Deficiencies of other minerals are not apparent for a long time. For example, a low calcium intake has no short-term consequences, but over the long term it reduces bone density, increasing the risk of fractures later in life.

Deficiencies of iron, iodine, and calcium cause health problems worldwide, whereas deficiencies of other minerals are rare, occurring only when the food supply is particularly limited or other factors affect mineral absorption or utilization.

Mineral toxicities occur most often as a result of environmental pollution or excessive use of supplements. For example, lead is toxic. Chronic exposure to lead from old lead paint, lead pipes, and soil and air contamination can cause growth retardation and learning disabilities in children (see Chapter 15). Even minerals such as iron that are essential in small doses can be toxic when consumed in excess.

What Affects Mineral Bioavailability? The bioavailability of the minerals in foods varies. For some minerals, such as sodium, almost all that is present in our food is absorbed, but for others, only a small percentage of what is consumed is absorbed. For instance, only about 25% of the calcium in our diet is absorbed, and iron absorption may be as low as 5%. How much of a particular mineral is absorbed and utilized may vary from food to food, meal to meal, and person to person.

In general, the minerals in animal products are better absorbed than those in plant foods. The difference in absorption is due in part to the fact that plants contain substances such as **phytates** (also called **phytic acid**), **tannins**, **oxalates**, and fiber that bind minerals in the gastrointestinal tract and can reduce absorption (Figure 11.3). The North American diet generally does not contain enough of any of these components to cause a mineral deficiency, but diets in developing countries may. For example, the amount of phytate in three-quarters of a cup of dry, unrefined cereal grains doubles the amount of zinc that needs to be consumed to meet needs.[1,2]

phytate or **phytic acid** A phosphorus storage compound found in seeds and grains that can bind minerals and decrease their absorption.

tannin A substance found in tea and some grains that can bind minerals and decrease their absorption.

oxalate An organic acid found in spinach and other leafy green vegetables that can bind minerals and decrease their absorption.

The presence of one mineral can also interfere with the absorption of another. For example, mineral ions that carry the same charge compete for absorption in the gastrointestinal tract. Calcium, magnesium, zinc, copper, and iron all carry a 2+ charge, so a high intake of one may reduce the absorption of another. Although this is generally not a problem when whole foods are consumed, a large dose of one mineral from a dietary supplement may interfere with the absorption of other minerals.

The body's need for a mineral may also affect how much of that mineral is absorbed. For instance, if plenty of iron is stored in your body, you absorb less of the iron you consume. Life stage can also affect absorption; for example, calcium absorption doubles during pregnancy, when the body's needs are high.

FIGURE 11.3 Compounds that interfere with mineral absorption
Plant foods such as these contain substances that can reduce mineral absorption when consumed in large amounts.

The ability to transport minerals from intestinal mucosal cells to the rest of the body also affects bioavailability. Some minerals must bind to plasma proteins or specific transport proteins to be transported in the blood. This binding helps regulate their absorption and prevents minerals that are chemically reactive from forming free radicals that could cause oxidative damage. Nutritional status and nutrient intake can affect mineral transport in the body. For instance, when protein intake is deficient, transport proteins (and proteins in general) cannot be synthesized. In this case, therefore, even if a mineral is adequate in the diet, it cannot be transported to the cells where it is needed.

How Minerals Function Minerals contribute to the body's structure and help regulate body processes. Many serve more than one function. For example, we need calcium to keep our bones strong and also to maintain normal blood pressure, allow muscles to contract, and transmit nerve signals from cell to cell. Some minerals help regulate water balance, others help regulate energy metabolism, and some affect growth and development through their role in the expression of certain genes. Many minerals act as **cofactors** needed for enzyme activity (Figure 11.4). None of the minerals we require acts in isolation. Instead, they interact with one another as well as with other nutrients and other components of the diet.

cofactor An inorganic ion or coenzyme required for enzyme activity.

Recommended Mineral Intakes As with other nutrients, the DRI recommendations for mineral intakes provide either an RDA value, when sufficient information is available to establish an EAR, or an AI, when population data are used to estimate needs. To help avoid toxic amounts of minerals, ULs have been established when adequate data are available. Recommendations are based on evidence from many types of research studies, ranging from laboratory studies done with animals and clinical trials using human subjects to epidemiological observations. In addition to planned experiments, information about trace mineral needs has come from the study of inherited diseases affecting trace mineral utilization and of individuals fed for long periods of time solely by total parenteral nutrition (TPN) solutions that were inadvertently deficient in specific essential minerals. As with other nutrients, when no other data are available, mineral needs can be estimated by evaluating the intake in a healthy population. If there are no signs of deficiency in the population, the diet is assumed to meet the requirement for that nutrient. One problem with this approach, however, is that deficiency symptoms may become apparent only when the deficiency is severe. Subtle signs of a mineral deficiency in a population may be difficult to detect, and deficiencies that have no symptoms for many years may be hard to identify.

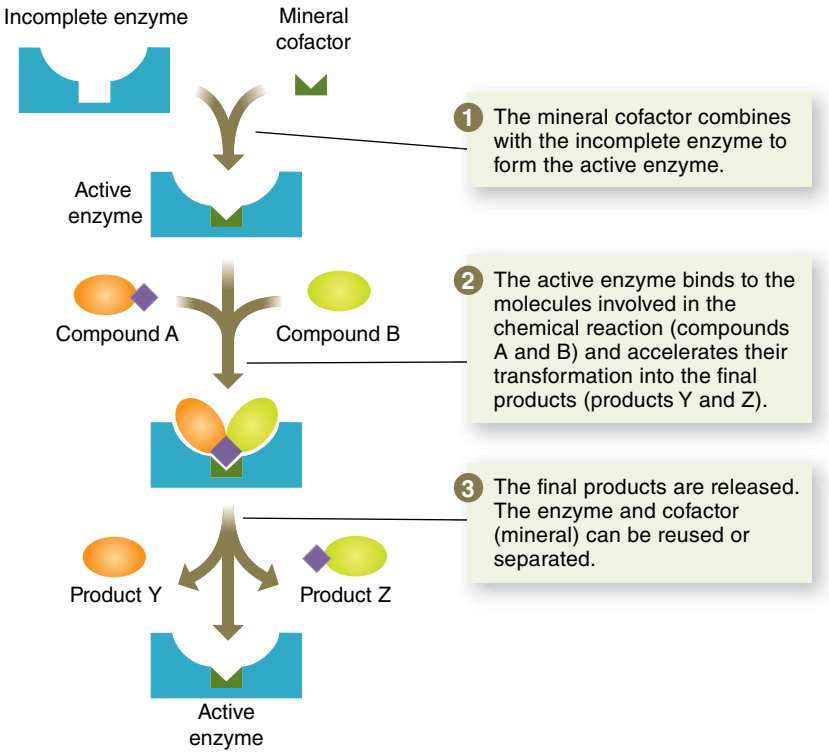


FIGURE 11.4 Mineral cofactors are needed for enzyme activity
Cofactors are helper molecules that participate in enzyme-catalyzed reactions. Some minerals serve as cofactors as shown here. Organic cofactors are called coenzymes and are discussed in Chapter 8.

11.2 Minerals, Osteoporosis, and Bone Health

LEARNING OBJECTIVES

- Explain the roles of protein, vitamin C, vitamin D, and calcium in bone formation.
- Explain why bone remodeling is important.
- Discuss how the rates of bone formation and breakdown change throughout life.
- Describe factors that affect the risk of osteoporosis.

osteoporosis A bone disorder characterized by a reduction in bone mass, increased bone fragility, and an increased risk of fractures.

Bones are the hardest, strongest structures in the human body. They are strong because of the minerals they contain—calcium along with phosphorus, magnesium, sodium, fluoride, and a number of others. Bones support our weight, whether we are walking, running, or jumping rope. However, with age, some bone is lost, causing bone strength to decrease. For many people, the loss of bone is so great that the force of stepping off a curb is enough to cause their bones to fracture. This condition is known as **osteoporosis**. Less severe loss of bone mass, called *osteopenia*, increases the risk of developing osteoporosis.[3]

hydroxyapatite A crystalline compound composed of calcium and phosphorus that is deposited in the protein matrix of bone to give it strength and rigidity.

Bone Structure, Formation, and Breakdown

Bone consists of a framework or matrix made up primarily of the protein collagen. Imbedded in this protein matrix are solid mineral crystals known as **hydroxyapatite**. Healthy bone requires adequate dietary protein and vitamin C to maintain the collagen and a sufficient supply of calcium and other minerals to ensure solidity. Adequate vitamin D (discussed in Chapter 9) is needed

to maintain appropriate levels of calcium and phosphorus. There is also growing evidence of the importance of vitamin K for bone health.[4]

There are two types of bone: **cortical** or **compact bone**, which accounts for about 80% of the skeleton and forms the sturdy, dense outer surface layer, and **trabecular** or **spongy bone**, which forms an inner lattice that supports the cortical shell (Figure 11.5A). Trabecular bone is found in the knobby ends of the long bones, the pelvis, wrists, vertebrae, scapulae, and the areas of the bone that surround the bone marrow.

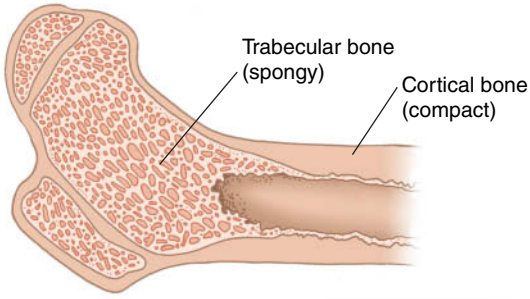
Like other tissues in the body, bone is alive, and it is constantly being broken down and re-formed through a process called **bone remodeling** (Figure 11.5B). Bone is formed by cells

cortical or **compact bone** Dense, compact bone that makes up the sturdy outer surface layer of bones.

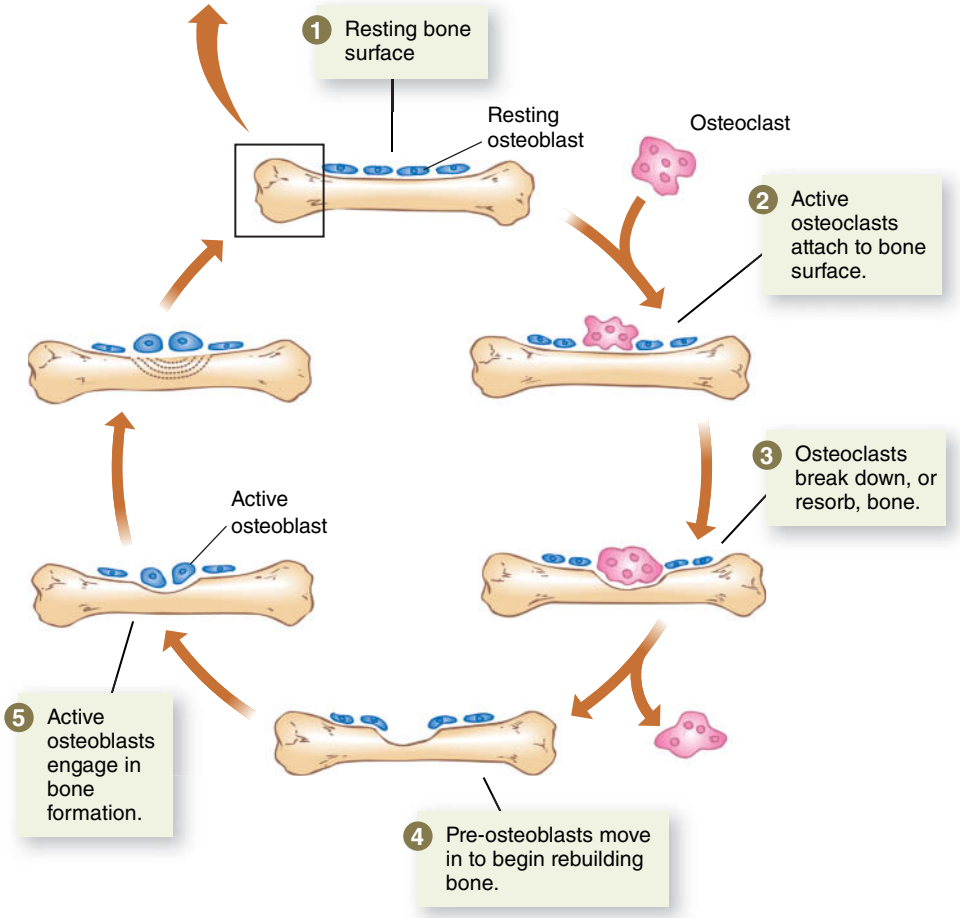
trabecular or **spongy bone** The type of bone forming the inner spongy lattice that lines the bone marrow cavity and supports the cortical shell.

bone remodeling The process whereby bone is continuously broken down and re-formed to allow for growth and maintenance.

FIGURE 11.5 Bone structure and remodeling



A. Cortical bone is compact bone that forms the dense outer layer; the spongy interior is referred to as trabecular bone.



B. During bone remodeling, osteoclasts (pink) break down bone and osteoblasts (blue) build bone.

osteoblast A type of cell responsible for the deposition of bone.

osteoclast A type of cell responsible for bone breakdown.

peak bone mass The maximum bone density attained at any time in life, usually occurring in young adulthood.

called **osteoblasts** and broken down in a process called *bone resorption* by cells called **osteoclasts**. During bone formation, the activity of the bone-building osteoblasts exceeds that of the osteoclasts. When bone is being broken down, the osteoclasts resorb bone more rapidly than the osteoblasts can rebuild it (see Figure 11.5B).

Most bone is formed early in life. In the growing bones of children, bone formation occurs more rapidly than breakdown. Even after growth stops, bone mass continues to increase into young adulthood when **peak bone mass** is achieved, somewhere between the ages of 18 and 30.[5] When bone breakdown and formation are in balance, bone mass remains constant. After about age 40, the amount of bone broken down begins to exceed that which is formed.[6] If enough bone is lost, the skeleton is weakened by osteoporosis and fractures occur easily.

Osteoporosis

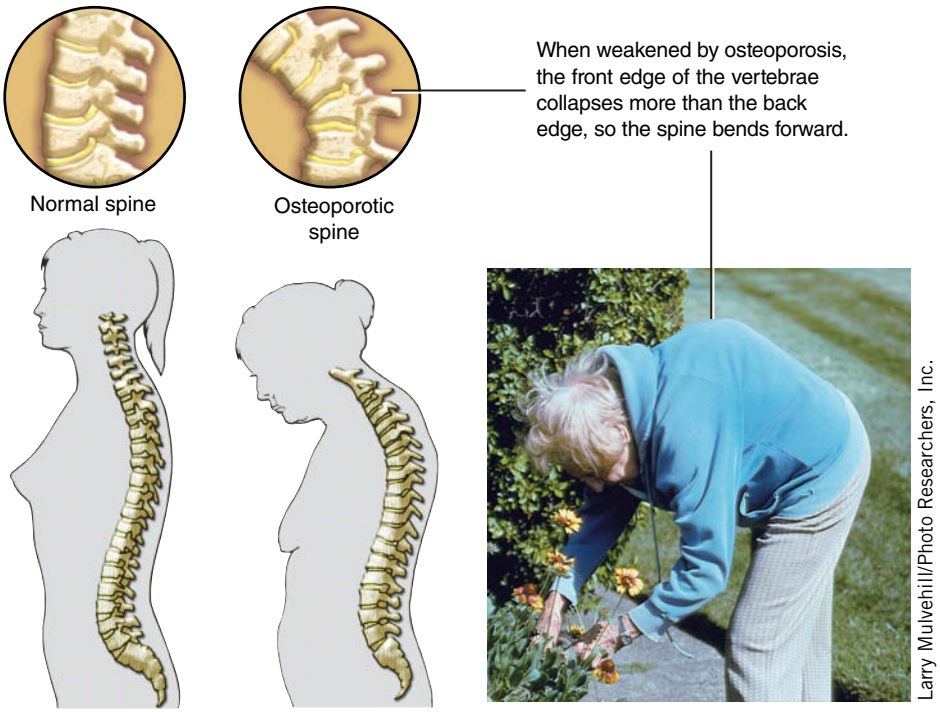
Osteoporosis is caused by a loss of both the protein matrix and the mineral deposits of bone, resulting in a decrease in the total amount of bone (Figure 11.6). Although both types of bone are lost with age, the greater surface area of the trabecular bone gives it a higher turnover rate than cortical bone and it is therefore more vulnerable to bone loss. As a result, the regions in the skeleton that have higher amounts of trabecular bone, such as the spine and the upper part of the femur, are more susceptible to fracture later in life.

Michael Klein/Photolibary/Getty Images

Osteoporosis Healthy Bone

FIGURE 11.6 Healthy bone versus osteoporosis
When trabecular bone is weakened by osteoporosis (left) it appears more porous than healthy bone (right).

How Osteoporosis Impacts Health Osteoporosis is a silent disease because it initially causes no symptoms. By the fifth or sixth decade of life, the bones of individuals with this disorder have weakened enough to cause back pain and bone fractures of the spine, hip, and wrist. Spinal compression fractures may result in loss of height and a stooped posture (called *dowager's hump*) (Figure 11.7). Osteoporosis is a major public health problem in the United States and around the world. In the United States, about 10.2 million people (8.2 million women and 2 million men) over age 50 have osteoporosis.[7] Osteoporosis leads to over 2 million fractures annually and accounts for nearly $20 billion per year in health care costs in the United States.[8] Combined, osteoporosis and osteopenia affect more than half of the total U.S. adult population. Worldwide, osteoporosis causes more than 8.9 million fractures annually; the equivalent of an osteoporotic fracture every 3 seconds.[9]



Larry Mulvehill/Photo Researchers, Inc.

FIGURE 11.7 Effects of osteoporosis
Spinal compression fractures, shown here, are common with osteoporosis and may result in loss of height and a stooped posture (called *dowager's hump*).

TABLE 11.1 Factors Affecting the Risk of Osteoporosis

Risk factor	How it affects risk
Gender	Fractures due to osteoporosis are about twice as common in women as in men. Men are larger and heavier than women and therefore have a greater peak bone mass. Women lose more bone than men due to postmenopausal bone loss.
Age	Bone loss is a normal part of aging, so the risk of osteoporosis increases with age.
Race	African Americans have denser bones than do Caucasians and Southeast Asians, so their risk of osteoporosis is lower.
Family history	Having a family member with osteoporosis increases risk.
Body size	Individuals who are thin and light have an increased risk because they have less bone mass.
Smoking	Tobacco use increases risk by reducing bone mass.
Exercise	Weight-bearing exercise, such as walking and jogging, throughout life strengthens bone, and increasing weight-bearing exercise at any age can increase bone density and decrease risk.
Alcohol abuse	Long-term alcohol abuse increases risk by reducing bone formation and interfering with the body's ability to absorb calcium.
Diet	A diet that is lacking in calcium and vitamin D increases the risk of osteoporosis. Low calcium intake during the years of bone formation results in a lower peak bone mass, and low calcium intake in adulthood can accelerate bone loss.

What Factors Affect the Risk of Osteoporosis? The causes of osteoporosis are not fully understood, but the risk depends on the level of peak bone mass and the rate at which bone is lost. These are affected by age, gender, hormone levels, genetics, and lifestyle (Table 11.1).

Why Risk Increases in Older Adults The risk of osteoporosis increases in adults as they age. This is because bone density declines after about age 40 when bone breakdown begins to exceed bone formation. This **age-related bone loss** occurs in both men and women and causes bone to be lost at a rate of about 0.5 to 1.0% per year (Figure 11.8).[10] The decrease in physical activity

age-related bone loss
The bone loss that occurs in both the cortical and trabecular bone of men and women as they advance in age.

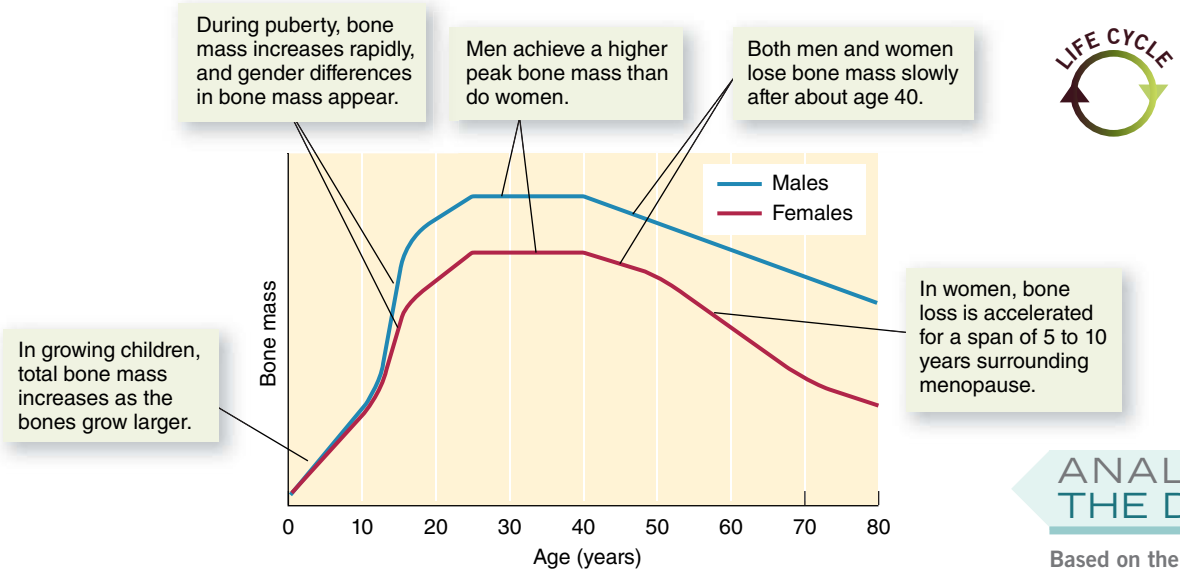


FIGURE 11.8 Bone mass by gender and age
Changes in the balance between bone formation and bone breakdown cause bone mass to increase in children and adolescents and decrease in adults as they grow older. Although both men and women lose bone after about age 40, women have a lower bone mineral density than men and experience accelerated bone loss during and after menopause.

ANALYZE THE DATA

Based on the information in this graph, why would women over age 50 be at greater risk of osteoporosis than men over 50?

that occurs as many adults age as well as factors that limit the availability of calcium and vitamin D, which is needed for calcium absorption, contribute to bone loss. In older adults there is a decrease in calcium and vitamin D intake, a reduction in dietary calcium absorption, a decrease in the efficiency of vitamin D activation by the kidney, and a reduction in skin production of vitamin D from sun exposure.[11] In addition, older adults typically spend less time in the sun and wear more clothing to cover the skin when outdoors, further decreasing the amount of vitamin D synthesized in the skin.

How Gender Affects Risk About 80% of those affected by osteoporosis are women.[7] Osteoporosis-related fractures occur in one out of every two women over age 50 compared to about one in every eight men over 50.[12] The risk of osteoporosis is greater in women than men because men have a higher peak bone mass to begin with and because bone loss is accelerated in women for a period of about 5 to 10 years surrounding **menopause** (see Figure 11.8). This **postmenopausal bone loss** is related to the drop in estrogen levels that occurs around menopause. Declining estrogen affects bone cells, allowing an increase in bone breakdown. It also decreases intestinal calcium absorption and reabsorption of calcium by the kidney.[10] During this 5- to 10-year period, bone loss increases to a rate of 2 to 3% per year. After the postmenopausal period, women continue to lose bone but at a slower rate.

menopause The physiological changes that mark the end of a woman's capacity to bear children.

postmenopausal bone loss Accelerated bone loss that occurs in women for about 5 to 10 years surrounding menopause.

How Your Genes Affect Bone Density It is estimated that 60 to 90% of the variability in bone mineral density in the population is inherited.[13] Family studies have revealed that children of individuals with osteoporotic bone fractures are more likely to have low bone density, and the risk of low bone density is higher in siblings of individuals with low bone density than in the general population.[13] Although our understanding of the genetics of osteoporosis in limited, the locations of a number of genes that are associated with bone mineral density and fracture risk have been identified.[13]

Lifestyle factors such as nutrition, activity level, smoking, and alcohol consumption interact with genetic factors over time to determine actual bone density. Genetic differences among racial groups lead to differences in the risk of osteoporosis. For example, the incidence of osteoporosis in African American women is about half that of white women, even though African American women have lower blood levels of vitamin D.[7,14] The reason for this lower risk of fractures is that African American women begin menopause with higher bone density and have lower rates of postmenopausal bone loss.[15]

Smoking and Alcohol Use Cigarette smoking and alcohol consumption both can decrease bone mass and increase the risk of bone fractures. It is estimated that smoking increases the lifetime risk of developing a hip fracture by 31% in women and 40% in men.[16] Smoking has direct effects on bone cells that reduce bone formation and increase bone resorption and indirect effects on hormone metabolism that further increase bone breakdown.[16] The effect of smoking may be partially reversed by smoking cessation. Some evidence suggests that moderate drinking may decrease the risk of fracture in postmenopausal women, but long-term heavy alcohol consumption has been clearly linked to bone loss and an increased risk of fractures.[16,17] In addition to direct effects on bone metabolism, alcohol consumption is typically accompanied by poor nutrition and malabsorption, which can contribute to bone loss.

Why Physical Activity Reduces Risk Weight-bearing exercise, such as walking and jogging, which puts direct weight over the skeleton, is good for bones. This mechanical stress stimulates the bones to become denser and stronger, increasing bone mass. In contrast, individuals who get no weight-bearing exercise, such as those with spinal cord injuries, those confined to bed, and astronauts in space, lose bone mass rapidly (see **Science Applied: Bone: Lost in Space**).

Regular weight-bearing physical activity is thought to be particularly important during childhood and adolescence because most of adult peak bone mass is accrued during this time. In premenopausal women, appropriate exercise programs have been found to preserve

SCIENCE APPLIED

Bone: Lost in Space

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

When John Glenn became the first American to orbit the Earth in 1962, there was little concern about the effect his five-hour flight would have on his bones. But by 1997, when Shannon Lucid spent 188 days aboard the Russian *Mir* space station, the effect of weightlessness on bone health had become a serious concern. Weight-bearing activities such as walking, jogging, and weight training are important for the maintenance of bone health. Under the force of Earth's gravity, these activities mechanically stress the bones, and this stimulates the deposition of calcium. When an astronaut goes into space, weightlessness eliminates this stimulus, calcium no longer accumulates in bone, and that present in bone upon leaving Earth's gravitational field begins to dissipate, elevating calcium levels in the rest of the body. This may lead to kidney stones and calcification of the soft tissues.[23] Unless bone loss in space can be prevented, prolonged space flights may not be possible.

NASA astronaut Dan Burbank exercises using the advanced Resistive Exercise Device (aRED) in the *Tranquility* node of the International Space Station.

THE SCIENCE

Information on bone loss in space has been accumulating for 60 years. Studies done in the 1960s and early 1970s during the *Gemini* and *Apollo* space missions first showed that astronauts lost calcium from their bones during space travel. *Skylab* missions then offered an opportunity to study the effects of more extended periods in zero gravity. In one study, nine astronauts maintained a constant dietary intake and made continuous urine and fecal collections for 21 to 31 days before their flight, during their *Skylab* missions, and for 17 to 18 days after returning to Earth. The results showed that urinary calcium losses were increased during the flight. These losses occurred despite vigorous exercise regimens while in flight and were comparable to losses seen in normal adults subjected to prolonged bed rest.[24]

In the 1990s, the *Mir* space station provided an opportunity for long-duration studies of bone metabolism in space.[25] The use of dual-energy X-ray absorptiometry (DXA) scans of astronauts and cosmonauts revealed that bone mineral density was decreasing at a rate of about 1.0 to 1.5% per month.[26] The most significant bone loss was found in weight-bearing parts of the skeleton: the lower vertebrae, hips, and upper femur—the same areas at risk for fracture in osteoporosis.[27] Once the astronauts returned to Earth, calcium loss slowed, but even after six months, bone mass in most subjects had not completely recovered.[28] Biochemical measures indicate that the bone loss that occurs during space flight is due to an increase in bone resorption and decreased intestinal calcium absorption.[23,25] The decrease in calcium absorption is likely due to low levels of vitamin D from insufficient dietary intake and lack of ultraviolet light exposure during space flight.[25]

In 2000, the first crews occupied the International Space Station, which was equipped with special resistance exercise equipment. The diet aboard the station provides 1000 to 1200 mg of calcium/day, as is recommended on Earth. Crews on *Skylab* consumed only about 900 mg/day.[29] It has also been determined that supplements of 800 IU/day of vitamin D maintain vitamin D levels during a six-month space mission.[30]

THE APPLICATION

By combining good nutritional intakes with heavy resistance exercise using a treadmill, cycle, and high-load resistance exercise devices (see photo), astronauts aboard the International Space Station were able to maintain their bone mineral density at preflight levels.[30] This occurred because the regimen increased bone formation. It failed, however, to decrease the space flight–induced bone resorption, leaving concerns about bone strength. Studies on astronauts continue to investigate other nutritional factors that affect bone metabolism such as omega-3 fatty acid intakes and appropriate levels of vitamin K, sodium, and protein.[29] What is optimal for bone health in space may be different from what is best for a healthy person living on Earth, but may be applicable to special populations at increased risk of bone loss. Understanding how to optimize nutrient intake and exercise patterns for bone mineral retention during long space flights will not only enhance our potential for space exploration, but also help people who are at risk of bone loss due to prolonged bed rest because of surgery, serious illness, or complications of pregnancy and those who are experiencing immobilization of some part of the body because of stroke, fracture, spinal cord injury, or other chronic conditions.

bone mineral density and reduce the risk of fractures.[18] Even in postmenopausal women, a high enough exercise frequency can lead to an increase in bone density.[19] Physical activity also improves muscle strength and balance, which can help reduce the risk of falls and fractures.

How BMI Affects Bone Density Having a BMI of less than 25 m/kg^2 increases the risk of fractures due to osteoporosis.[20,21] This is because low body weight does little to stimulate the bones to become denser. In contrast, greater body weight increases bone mass by increasing the amount of weight the bones must support in day-to-day activities. Obesity, therefore, could be considered protective against osteoporosis. In fact, elevated body weight and BMI are correlated with an increase in bone density and a reduced risk of fractures.[22] In postmenopausal women, excess body fat may also reduce risk because adipose tissue produces estrogen, which helps maintain bone mass and enhances calcium absorption.

Despite these positive effects on bone health, obesity is now recognized to also have some detrimental effects on bone density. Obesity increases inflammation, which increases bone resorption.[22] Individuals with obesity have lower vitamin D levels because the vitamin is sequestered in their adipose tissue. This causes hormonal changes that contribute to bone resorption. A number of studies have found obesity to be associated with an increase in fractures at certain locations.[22] Whether obesity is beneficial or detrimental to bone health may vary with the amount and location of body fat, the age and gender of the individual, and the portion of the skeleton being assessed.

How Diet Affects Osteoporosis Risk Diet can have a significant effect on osteoporosis risk. Adequate calcium intake is important for bone development and bone health throughout life. During childhood and adolescence, adequate calcium intake is needed to maximize bone density; low calcium intakes during the years of bone formation result in a lower peak bone mass. If calcium intake is low after peak bone mass has been achieved, the rate of bone loss may be increased and, along with it, the risk of osteoporosis.

Despite its importance, calcium intake is not the only dietary factor that affects the risk of osteoporosis. Other dietary components alter bone mass and bone health by changing calcium absorption, urinary calcium losses, and bone physiology. Low intakes of vitamin D reduce calcium absorption, thereby increasing the risk of osteoporosis. Diets high in phytate, oxalates, and tannins also reduce calcium absorption. High sodium has been implicated as a risk factor for osteoporosis because high dietary sodium intake increases calcium loss in the urine.[31] Adequate protein is necessary for bone health, but increasing protein intake increases urinary calcium losses. Despite this, high protein intakes are generally not associated with a higher risk of osteoporosis. This is because diets higher in protein are typically higher in calcium and may enhance calcium absorption. Bone mass depends more on the ratio of calcium to protein than the amount of protein alone. When intakes of calcium and vitamin D are adequate, neither high protein nor high sodium is believed to adversely affect bone health and the risk of osteoporosis.[32,33] In addition to the effect of individual nutrients, healthy dietary patterns, which are plentiful in fruits and vegetables, are associated with greater bone mass and a lower risk of fractures (see **Critical Thinking: Osteoporosis Risk**).[34]

How to Prevent and Treat Osteoporosis

You can't feel your bones weakening, so people with osteoporosis may not know that their bone mass is dangerously low until they are in their 50s or 60s and experience a bone fracture. Once osteoporosis has developed, it is difficult to restore lost bone. Therefore, the best treatment for osteoporosis is to prevent it by achieving a high peak bone mass and slowing the rate of bone loss. During childhood, adolescence, and young adulthood, diet and exercise can help prevent osteoporosis by ensuring maximum peak bone density. A diet that contains adequate amounts of calcium and vitamin D produces greater peak bone mass during the early years and slows bone loss as adults age. Adequate intakes of zinc, magnesium, potassium, fiber, vitamin K, and vitamin C—nutrients that are plentiful in fruits and vegetables—are also important for bone health. Weight-bearing exercise before about age 35 helps to increases peak bone mass, and maintaining an active lifestyle that includes weight-bearing exercise throughout life helps preserve bone density. Limiting smoking and alcohol consumption can also help to increase and maintain bone density.

CRITICAL THINKING

Osteoporosis Risk

Vezzani Photography / Shutterstock

Sylvia is worried about her risk for osteoporosis. Her 75-year-old mother recently suffered a fractured hip due to reduced bone density caused by osteoporosis. Her previously independent mother is now living in a nursing home and struggling to return to her former life. Sylvia is frightened that she will face the same future. To assess her risk, she completes an osteoporosis risk factor questionnaire from a health magazine and uses a phone app to determine her calcium and vitamin D intake.

ARE YOU AT RISK FOR OSTEOPOROSIS?	
Gender?	Female
Age?	42
Have you ever broken a bone?	No
Have you gone through menopause?	No
What is your bone density?	Never been measured
Do you have a family history of osteoporosis?	Yes
What is your body mass index?	27.5 kg/m^2
Do you smoke cigarettes?	Yes
How much alcohol do you drink?	3 drinks per week
How many servings of dairy do you eat?	Fewer than 1 per day
How many servings of dairy did you eat as a child?	2 or fewer per day
How many servings of leafy green vegetables do you eat?	1 per week
Do you take a calcium supplement?	No
What is the type and frequency of the exercise you get?	Tennis once a week
What is your exercise history?	I was active as a child but no longer exercise often.

CRITICAL THINKING QUESTIONS

- **What foods, other than dairy products, could Sylvia add to her diet to increase her calcium intake? Would these increase her vitamin D intake?**
- **How might she increase the amount of vitamin D in her body?**
- **Do you think she should take a calcium supplement? Why or why not?**

List six factors that put Sylvia at risk for osteoporosis.

Sylvia's diet analysis shows that her average calcium intake is 820 mg/day and her vitamin D intake is 8 μg/day. How much more of each would she need to consume to meet the RDA?

iProfile Use iProfile to find out how much calcium is provided by the nondairy foods in your diet.

Supplements of calcium and vitamin D are currently used by many people, particularly women, to prevent and treat osteoporosis (see **Debate: Are Supplements a Safe Way to Meet Your Calcium Needs?**). The U.S. Preventive Service Task Force has recently concluded that there is insufficient evidence to recommend calcium and vitamin D supplements to prevent osteoporosis in healthy men and women.[35] Supplementation may, however, be beneficial in some individuals who already have osteoporosis and in those who are unable to obtain adequate dietary calcium.

DEBATE

Are Supplements a Safe Way to Meet Your Calcium Needs?

Calcium is essential for bone health, but many of us don't consume the recommended amount in our diets; about one third of American adults rely on calcium supplements.[37,38] These help us meet the RDA, but now several studies have suggested that calcium supplementation may increase the risk of cardiovascular disease. Will the calcium you take to keep your bones strong cause a heart attack? Should you supplement calcium?

Francoise Sauze/Photo Researchers, Inc.

Calcium supplements are important for some people, but the 2011 DRIs for calcium caution that oversupplementation may be causing many postmenopausal women to be getting too much calcium.

The reason calcium supplements may increase the risk of cardiovascular disease is still unknown, but it is hypothesized to be related to the fact that calcium supplements cause a rise in blood calcium levels after ingestion. Since the atherosclerotic deposits that lead to heart attacks are hardened by calcium, elevated blood levels have been hypothesized to cause calcium to be transferred to the artery wall.[39] High blood calcium may also affect blood clotting and blood pressure. An analysis of multiple calcium supplementation trials found about a 30% increase in the incidence of heart attacks in patients taking the supplements compared to the controls.[40] A similar effect was seen in a study that supplemented calcium and vitamin D.[41]

Some argue that the studies had flaws in the way the calcium supplementation data was analyzed and that the evidence does not support tossing your calcium supplements to reduce heart disease risk. For example, another study found that over 7 years calcium and vitamin D supplements in postmenopausal women reduced the risk of hip fracture by 35% without an increase in cardiovascular disease.[42] Likewise, when data on 74,245 women who took part in the Nurses' Health Study was examined, after 24 years of follow-up there was no significant difference in the rate of heart attack or stroke between women who took more than 1000 mg of calcium a day and those who took none.[43] Based on a recent analysis that included over 63,000 subjects, the International Osteoporosis Foundation has concluded that supplemental calcium, with or without vitamin D, does not increase the risk of heart disease.[44] To better understand the relationship between calcium supplements and cardiovascular events, trials need to be designed to specifically examine this issue.

There is strong evidence that adequate calcium intake throughout life reduces the risk of osteoporosis, but this does not necessarily mean that adding a calcium supplement in adulthood will have the same effect. When combined with vitamin D, calcium supplements can reduce the incidence of bone fractures in certain populations, but further study is required to determine optimal dose and dosing regimens.[45] In the United States 85.6 million people suffer from cardiovascular disease,[46] whereas, only 10.2 million have osteoporosis.[7] Some suggest that if you consider the overall benefits and risks of calcium supplements in the population, the number of cardiovascular events caused by calcium supplements may actually be greater than the number of fractures prevented.[39,47]

So do calcium supplements increase heart attack risk? Are you increasing your osteoporosis risk by not taking supplements? Everyone agrees that getting adequate calcium from food is the best option. It is absorbed more slowly, so it does not cause a rapid rise in blood calcium. High calcium intake from foods is not associated with heart disease; it may even be associated with a lower risk of cardiovascular disease.[48] In postmenopausal women, the group with the highest risk of osteoporosis, typical calcium intake is about 900 mg and over 35% of this may come from supplements.[37] If these women do not take supplements they are getting only about half of the RDA. Are supplements worth the risk?

THINK CRITICALLY: What dietary changes would you suggest to maintain bone health in a teenage girl who is consuming 600 mg of calcium per day from food?

Osteoporosis is commonly treated with drugs that prevent bone resorption. One class of drugs, called bisphosphonates, inhibits the activity of cells that break down bone. Bisphosphonates have been shown to prevent postmenopausal bone loss, increase bone mineral density, and reduce the risk of fractures.[36] Another class of drugs, called selective estrogen receptor modulators (SERMs), provides the benefits of estrogen (reduced bone breakdown and increased calcium absorption) without its negative side effects, such as increasing the risk of heart disease and some types of cancer.

11.3 Calcium (Ca)

LEARNING OBJECTIVES

- List foods that are good sources of calcium.
- Explain the functions of calcium in the body.
- Compare the roles of parathyroid hormone, calcitonin, and vitamin D in the regulation of blood calcium levels.

Calcium is the most abundant mineral in the body. It provides structure to bones and teeth and has essential regulatory roles. Because of the importance of calcium in regulating body processes, blood levels of this mineral are strictly controlled. However, this occurs at the expense of bone calcium; calcium is released from bone when blood levels drop. As a result, if the diet is not sufficient in calcium, over the long term, the amount of calcium in bone declines and the risk of bone fractures due to osteoporosis is increased.

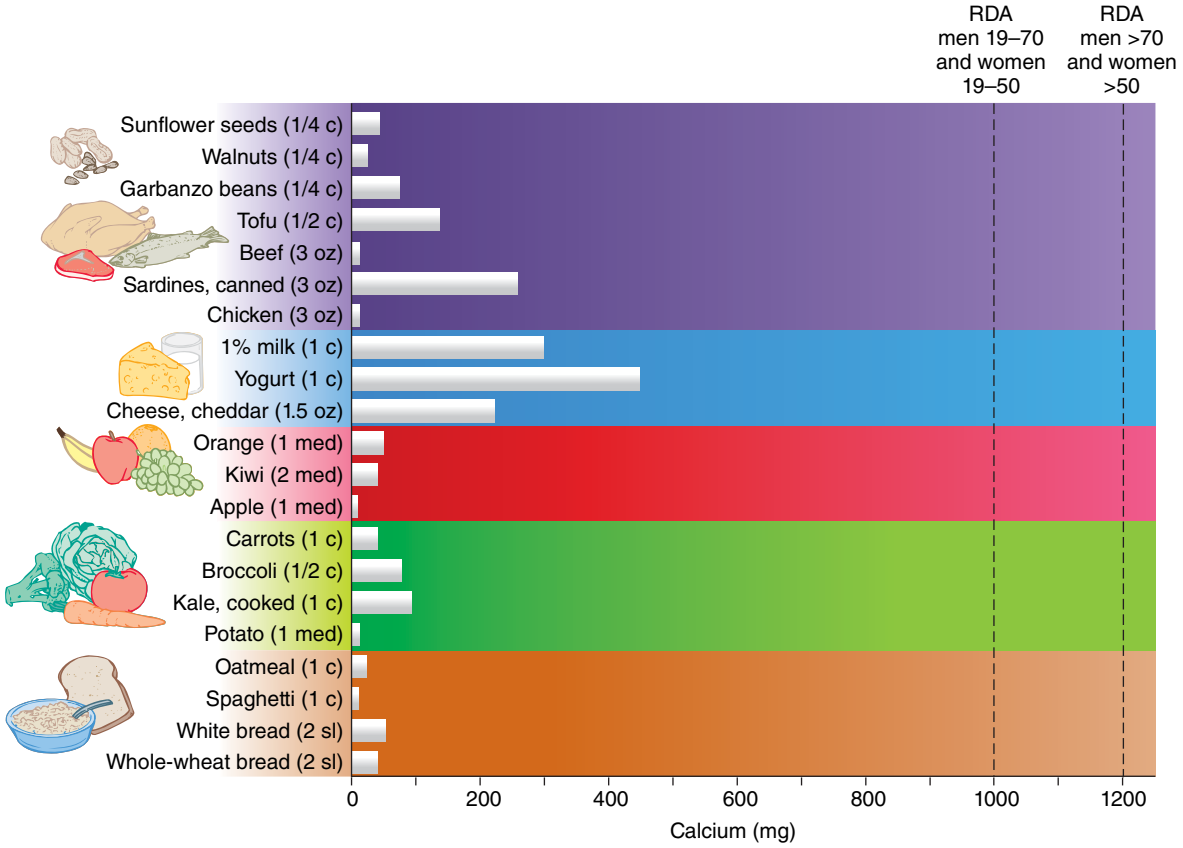


FIGURE 11.9 Calcium content of MyPlate food groups
Calcium is provided by many different foods, but dairy products and fish consumed with bones are the best sources; the dashed lines represent the RDAs for adult men and women.

THINK CRITICALLY

If bioavailability were the same, how much cooked kale would you need to eat to get as much calcium as you do from a cup of milk?

Calcium in the Diet

The main source of calcium in the U.S. diet is dairy products such as milk, cheese, and yogurt. Fish, such as sardines, that are consumed in their entirety, including the bones, are also a good source, as are legumes and some green vegetables such as broccoli, Chinese cabbage, and kale (Figure 11.9). Grains provide smaller amounts of calcium, but because they are consumed in such large quantities, they make a significant contribution to dietary calcium intake.

Some of the calcium in the diet may come from supplements or be added to foods during food processing. Baked goods such as breads, rolls, and crackers, to which nonfat dry milk powder has been added, provide calcium, as do tortillas that are treated with lime water (calcium hydroxide). Tofu is a good source when calcium is used in its processing. In addition, numerous products on the market, such as orange juice and breakfast cereals, are fortified with calcium.

Calcium in the Digestive Tract

Calcium is absorbed by both active transport and passive diffusion (Figure 11.10). Active transport depends on the availability of the active form of vitamin D, which turns on the synthesis of calcium transport proteins in the intestine. Active transport accounts for most calcium absorption when intakes are low to moderate. At high calcium intakes, passive diffusion becomes more important. As calcium intake increases, the percentage that is absorbed declines. Both active and passive absorption require stomach acid. The acid causes the calcium to dissolve, forming calcium ions (Ca^{2+}) that can be absorbed.[49]

The efficiency of calcium absorption is higher at times when the body's need for calcium is greater. During pregnancy, when calcium is needed for formation of the fetal skeleton, elevated estrogen helps increase calcium absorption to over 50%. Calcium need is also increased during lactation, but some of the calcium needed to make milk appears to come from the mother's bones. After lactation stops, an increase in calcium absorption and retention of calcium by the kidney help restore bone calcium. During infancy, when the skeleton is growing

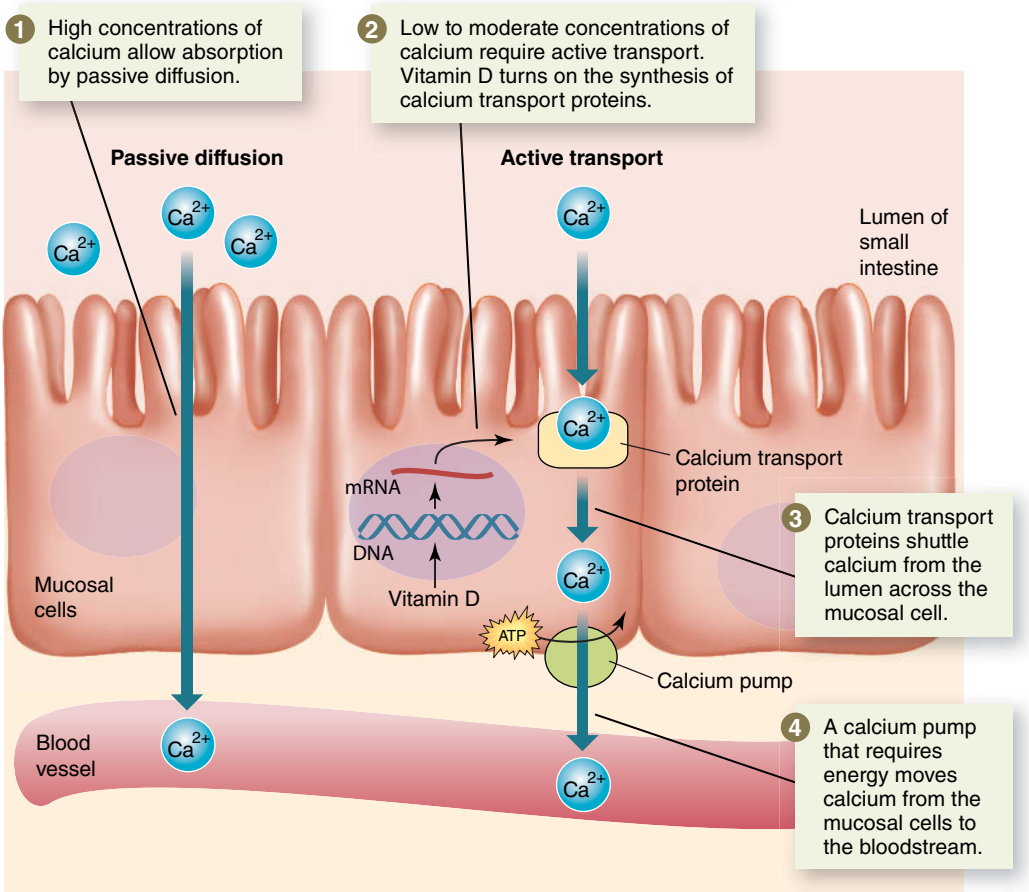


FIGURE 11.10 Calcium absorption
Some calcium can be absorbed by passive diffusion, particularly when calcium concentrations are high. At lower calcium concentrations, absorption occurs primarily by an active transport mechanism that requires vitamin D.

rapidly, about 60% of calcium consumed is absorbed. In young adults, absorption is about 25%. In older adults, absorption declines. This may be due to a reduction in stomach acid, a decrease in blood levels of the active form of vitamin D, or a decrease in responsiveness to vitamin D.[11] An additional decrease in calcium absorption occurs in menopausal women due to the decrease in estrogen.

The bioavailability of calcium is affected by a number of dietary factors, the most significant of which is vitamin D. When vitamin D is deficient, absorption drops to about 10%.[50] Calcium absorption is increased by the presence of acidic foods, lactose, and fat, and decreased by tannins, fiber, phytates, and oxalates. For example, spinach is a high-calcium vegetable but, only about 5% of its calcium is absorbed; the rest is bound by oxalates and excreted in the feces.[51] Vegetables such as kale, collard greens, turnip greens, mustard greens, and Chinese cabbage are low in oxalates, so their calcium is well absorbed. Chocolate also contains oxalates, but chocolate milk is still a good source of calcium because the amount of oxalates from the chocolate added to a glass of milk is small. Fiber can also reduce calcium absorption, but with few exceptions, the effect is small. Phytates, however, can have a significant effect on the absorption of calcium from foods such as wheat bran and pinto, red, and white beans. It would take almost 10 servings of red beans to provide the same amount of absorbable calcium as 1 serving of milk. When calcium intake is low, dietary components that alter absorption have a greater effect on calcium status than when calcium intake is adequate.

Medications that reduce the secretion of stomach acid, such as H2 blockers (e.g., Pepcid AC and Zantac) and proton pump inhibitors (e.g., Prilosec and Prevacid), can also interfere with calcium absorption. These are used to treat heartburn and gastroesophageal reflux disease (GERD) and may be taken over long periods. By blocking stomach acid secretion, they reduce calcium absorption and may contribute to the development of osteoporosis in the long term.[49]

How Calcium Functions in the Body

Calcium accounts for 1 to 2% of adult body weight. Over 99% of the calcium in the body is found in the solid mineral deposits in bones and teeth.[50] The remaining 1% is present in intracellular fluid, blood, and other extracellular fluids, where it plays vital roles in nerve transmission, muscle contraction, blood pressure regulation, and the release of hormones.

Regulatory Roles of Calcium The calcium in body fluids plays critical roles in cell communication and the regulation of body processes. Calcium helps regulate enzyme activity and is necessary in blood clotting. It is involved in transmitting chemical and electrical signals in nerves and muscles. It is necessary for the release of neurotransmitters, which allow nerve impulses to pass from one nerve to another and from nerves to target tissues. Inside the muscle cells, calcium allows the two muscle proteins, actin and myosin, to interact to cause muscle contraction. The importance of calcium for proper nerve transmission and muscle contraction is illustrated by what happens when the concentration of calcium in the extracellular fluid drops too low. When this occurs, the nervous system becomes increasingly excitable and nerves fire spontaneously, triggering contractions of the muscles, a condition known as *tetany*. Mild tetany can cause tingling of the lips, fingers, and toes, and more serious tetany results in severe muscle contractions, tremors, cramps, and even death. Tetany is typically caused by hormonal abnormalities, not a dietary calcium deficiency.

Calcium also plays a role in blood pressure regulation, possibly by controlling the contraction of muscles in the blood vessel walls and signaling the secretion of substances that regulate blood pressure. The impact of adequate calcium on maintaining healthy blood pressure was demonstrated by the DASH trial (see Chapter 10, *Science Applied: A DASH to Heart Health*). In this trial, a diet high in potassium, magnesium, and calcium was found to be more effective at lowering blood pressure than the control diet or an experimental diet lower in calcium.[52] Following the recommendations of the DASH Eating Plan can help keep both bones and blood pressure healthy.

How Blood Calcium Levels Are Regulated The roles of calcium are so vital to survival that powerful regulatory mechanisms ensure that constant intracellular and extracellular concentrations are maintained. Slight changes in blood calcium levels trigger responses that quickly raise

THINK CRITICALLY

When blood calcium is normal, PTH levels are low. How does this affect the amount of calcium excreted in the urine and the amount absorbed from the GI tract?

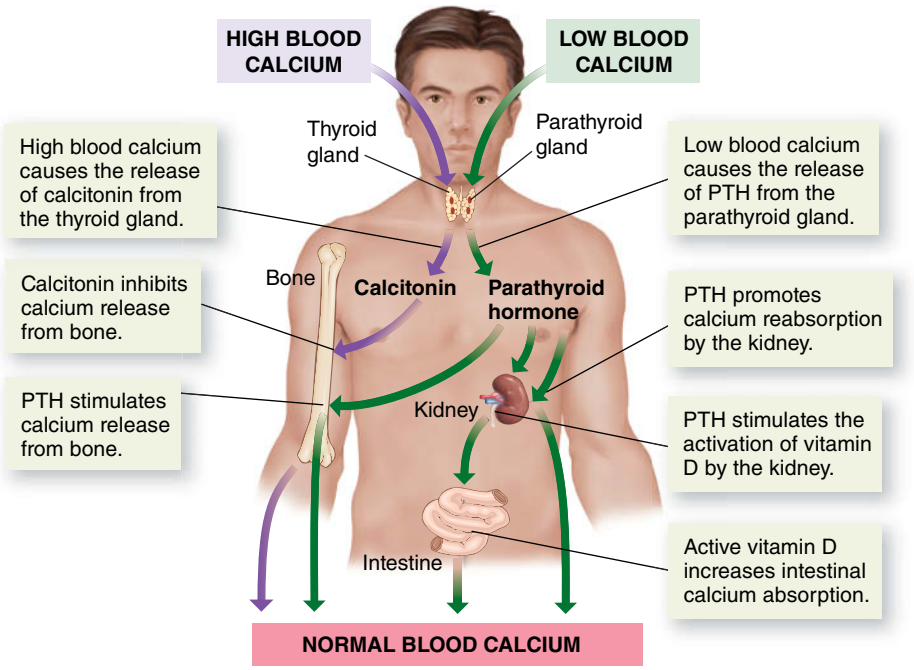


FIGURE 11.11 Regulation of blood calcium levels
Levels of calcium in the blood are very tightly regulated by parathyroid hormone and calcitonin.

parathyroid hormone (PTH) A hormone secreted by the parathyroid gland that increases blood calcium levels.

calcitonin A hormone secreted by the thyroid gland that reduces blood calcium levels.

or lower them back to normal. The hormones **parathyroid hormone (PTH)**, which raises blood calcium, and **calcitonin**, which lowers blood calcium, help maintain calcium homeostasis (Figure 11.11). If the level of blood calcium falls too low, it triggers an increase in the secretion of PTH from the parathyroid glands. PTH stimulates the release of calcium from bone and causes the kidneys to reduce calcium loss in the urine and to activate vitamin D. Activated vitamin D increases the amount of calcium absorbed from the gastrointestinal tract and acts with PTH to stimulate calcium release from the bone and calcium retention by the kidney (see Chapter 9). The overall effect is to rapidly increase blood calcium levels. If blood calcium levels become too high, the secretion of PTH is reduced. This increases excretion of calcium by the kidney, decreases vitamin D activation so less dietary calcium is absorbed, and reduces calcium release from bone. High blood calcium also stimulates the secretion of calcitonin from the thyroid gland. Calcitonin acts primarily on bone to inhibit the release of calcium. Together, low PTH levels and the presence of calcitonin cause blood calcium levels to decrease to normal (see Figure 11.11).

Calcium Deficiency

When calcium intake is not adequate, normal blood levels are maintained by resorbing calcium from bone. This provides a steady supply of calcium to support cell communication, nerve transmission, muscle contraction, and other regulatory roles. Although there are no short-term symptoms of a calcium deficiency related to the removal of calcium from bone, a deficient diet affects bone mass. Low calcium intake during the years of bone formation results in lower bone density. Low intake during the adult years increases the rate of bone loss. As discussed previously, both of these effects increase the risk of osteoporosis.

Recommended Calcium Intake

For adults 19 to 50 years old, 1000 mg/day of calcium is recommended to maintain bone health. Because menopause increases the rate of bone loss, the RDA for women ages 51 to 70 is set at 1200 mg/day to slow bone loss. For men in this age group it remains at 1000 mg/day. Bone loss and resulting osteoporotic fractures are concerns for both men and women ages 70 and older, so the RDA for both genders in this age group is 1200 mg/day.[53] In children and adolescents the RDA is set at a level that supports bone growth. For adolescents the RDA is higher than for adults—1300 mg/day for boys and girls ages 9 through 18 years.

Infants thrive on the amount of calcium they obtain from human milk. For infants, an AI is set based on the calcium content of human milk. The RDA for calcium during pregnancy is the same as for nonpregnant women. This is because there is an increase in maternal calcium absorption during pregnancy that helps to supply the calcium needed for the fetal skeleton. The RDA during lactation is the same as for nonlactating women even though calcium is secreted in milk. The source of this calcium does appear to be the maternal skeleton, but this bone resorption occurs regardless of calcium intake and the calcium lost appears to be regained following weaning.[54]

LIFE CYCLE

THINK CRITICALLY

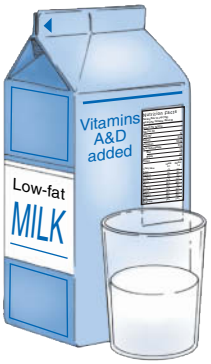
How do you think the trend away from milk consumption will affect the incidence of osteoporosis 30 years from now?

Meeting Calcium Needs

The best way to meet calcium needs is with food. Food provides you with other nutrients, some of which are important for absorbing and using calcium. For those who are unable to obtain adequate calcium from natural food sources, fortified foods and supplements may be necessary.

Getting Enough Calcium from Food Milk is the major source of calcium in the U.S. diet, but milk consumption has been declining. Many people have replaced milk with sugar-sweetened sodas; 48% of American adults consume soda daily.[55] Among children sugar-sweetened beverage intake has also increased, and the greatest consumers are teenage boys and girls who get about 13% of their calories from soda and other sugar-sweetened beverages.[56] This shift from milk to sugar-sweetened beverages has significantly reduced calcium intake (Figure 11.12), which is currently below recommendations, especially among adolescent girls and adults.[7] Both the DASH Eating Plan and MyPlate recommend 3 cups of milk or milk products plus 2 to 5 cups of vegetables daily to ensure adequate calcium intake (see **Off the Label: How Much Calcium Is in Your Yogurt?**).

Individuals who do not consume animal products can meet their calcium needs with plant sources such as kale, broccoli, mustard greens, and other dark-green vegetables; soy products processed with calcium; and calcium-fortified foods such as breakfast cereals and juice products (Figure 11.13). Individuals who don't



	Low-fat milk	Cola soft drink
Serving size (oz)	8	12
Energy (kcal)	102	150
Protein (g)	8	0
Calcium (mg)	300	0
Phosphorus (mg)	235	45
Riboflavin (mg)	0.4	0
Vitamin A (μg)	144	0
Vitamin D (μg)	3	0
Caffeine (mg)	0	40

FIGURE 11.12 Soda versus milk
A 12-oz can of soda contains about 10 tsp of sugar and few other nutrients. Replacing a glass of milk with a soda increases the amount of added sugar in the diet by about 40 g and reduces protein, calcium, vitamin A, vitamin D, and riboflavin intake.

FIGURE 11.13 Dietary sources of calcium

Felicia Martinez/PhotoEdit

A. Dairy products, fish consumed with bones, leafy greens, and legumes are good sources of calcium.

Andy Washnik

B. A variety of calcium-fortified foods are available to help meet needs. A cup of calcium-fortified orange juice or soymilk provides as much calcium as a glass of milk.

OFF THE LABEL

How Much Calcium Is in Your Yogurt?

© iStockphoto

How much calcium is in your yogurt? How much vitamin C is in your orange juice? And how much iron is in a box of raisins? Using the current Nutrition Facts label it can be difficult to tell exactly how much of a micronutrient (except sodium) is in a food. Current food labels are required to provide the % Daily Values for vitamin A, vitamin C, iron, and calcium, but not the actual amount. Daily Values for other vitamins and minerals are provided voluntarily on some foods. To determine the amount of a vitamin or mineral in a serving of food using the current food label, you need to look up its Daily Value (see Appendix B). Once you know the Daily Value, you can multiply it by the % Daily Value on the label to determine the amount in a serving of the food. So, using the current Nutrition Facts label on the left, follow these steps to find out how much calcium is in a serving of yogurt:

1. Look up the Daily Value in Appendix B: The Daily Value for calcium is 1000 mg.
2. Find the % Daily Value (%DV) on the food label (see figure): %DV for calcium in a serving of this yogurt = 15%.
3. Multiply the % Daily Value by the Daily Value to find out how much is in a serving: 1000 mg × 15% = 1000 × 0.15 = 150 mg calcium.

Proposed changes to food labels (see label on the right) will make figuring out how much calcium is in a food easier because it will include the actual amount in milligrams as well as the %DV. The proposed Nutrition Facts panel will be required to include vitamin D, calcium, iron, and potassium, because these are now considered nutrients of public health concern. The Daily Values will also be updated to reflect our current understanding of nutrient needs.

Even if you don't look up the Daily Value and calculate the exact amount of calcium or some other vitamin or mineral in a food, the % Daily Value on the current food label helps you judge how much the food contains. As a general guideline, if the % Daily Value of a nutrient is 5% or less, the food is a poor source of that nutrient; if it is 10 to 19%, the food is a good source; and if it is 20% or more, the food is an excellent source. Descriptors such as "high in calcium" or "a good source of calcium" can help you identify foods that make a significant calcium contribution (see table). Foods high in calcium may include the health claim that a diet high in calcium helps reduce the risk of osteoporosis.

Calcium Descriptors on Food Labels

Descriptor	Definition
High calcium, rich in calcium, excellent source of calcium	Contains 200 mg of calcium or more per serving
Good source of calcium	Contains 100 to 190 mg of calcium per serving
More or added calcium	Contains at least 100 mg more calcium per serving than a reference food

Current label

Nutrition Facts
Servings 1 Container

Amount Per Serving

Calories 90	Calories from Fat 0
	%Daily Value**
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	
Cholesterol <5mg	1%
Sodium 80mg	3%
Total Carbohydrate 23g	8%
Sugars 23g	
Protein 5g	10%

Vitamin A 15% • Calcium 15%
Vitamin D 20% • Phosphorus 10%

Not a significant source of dietary fiber, vitamin C and iron

*Percent Daily Values are based on a 2,000 calorie diet.

Tom Grill / Getty Images, Inc.

Proposed label

Nutrition Facts
1 servings per container
Serving size 1 container

Amount per 6 oz
Calories **90**

%DV*	
0%	**Total Fat** 0g
0%	**Saturated Fat** 0g
	***Trans* Fat** 0g
0%	**Cholesterol** 0mg
3%	**Sodium** 80mg
8%	**Total Carbs** 23g
0%	**Dietary Fiber** 0g
	Sugar 23g
	Added sugar 10g
	Protein 5g
20%	**Vitamin D** 4mcg
15%	**Calcium** 150mg
0%	**Iron** 0g
11%	**Potassium** 375g

*Footnote on Daily Values (DV) and calories reference to be inserted here.

consume dairy products, but do eat other animal products, can also get calcium from fish consumed with the bones. Individuals who do not consume milk because they are lactose intolerant may be able to get calcium by consuming fermented dairy products such as yogurt and cheese, which are lower in lactose than milk. They can also meet their calcium needs by drinking milk treated with the lactose-digesting enzyme lactase, taking lactase tablets to help digest the lactose consumed with a meal (see Chapter 4), or by consuming calcium-fortified foods.

When Is Supplemental Calcium Recommended? Because of concerns about the safety of calcium supplements and limited data on their benefits (see *Debate: Are Supplements a Safe Way to Meet Your Calcium Needs?*), fortified foods are recommended to meet the RDA for calcium in those who are unable to do so with natural food sources.[7] Despite this, calcium supplements may still be recommended for individuals who cannot meet their calcium needs with diet alone.

If you take calcium supplements, the form of calcium in the supplement and the amount per dose affect how much you absorb. Calcium is present in foods and supplements as a compound with other molecules. During digestion, the calcium compound dissolves and the calcium ions become available for absorption. Calcium citrate and calcium carbonate are calcium compounds commonly found in supplements. Calcium carbonate is 40% calcium by weight and 60% carbonate. Other calcium compounds such as calcium phosphate, calcium lactate, and calcium gluconate have much smaller percentages of calcium, so you would need to consume more tablets per day to get the same dose. Dolomite, oyster shell, and bone meal are natural sources of calcium that may be contaminated with heavy metals such as lead. The FDA has set an upper limit as to the amount of lead a calcium supplement may contain, but it is up to the manufacturer to determine if their supplement meets FDA standards.

Because calcium absorption decreases when large amounts are consumed at one time, calcium bioavailability is better when a lower-dose calcium supplement (no more than 500 mg per dose) is taken twice a day than when a supplement that provides 100% of the RDA is taken once a day.

Excessive Calcium

Too much, as well as too little, calcium can cause health problems. Elevated blood calcium levels can cause symptoms such as loss of appetite, nausea, vomiting, constipation, abdominal pain, thirst, and frequent urination. Severe elevations may cause confusion, delirium, coma, and even death. Elevated blood calcium is rare and is most often caused by cancer or disorders that increase the secretion of PTH rather than intake from diet or supplements. But it can also result from increases in calcium absorption due to excessive vitamin D intake or a high intake of calcium in combination with antacids. Consuming large amounts of milk along with antacids used to be a common treatment for peptic ulcers. This combination is associated with a condition called *milk-alkali syndrome*, which is characterized by high blood calcium along with calcification of the kidney that can lead to kidney failure. After the treatment of ulcers changed, the incidence of this condition declined, but it has risen again due to the increased use of calcium-containing antacids as calcium supplements and to treat heartburn.[57]

Too much calcium from supplements may also promote the formation of kidney stones. Kidney stones, which are usually composed of calcium oxalate or calcium phosphate, affect approximately 12% of the U.S. population. Although their cause is usually unknown, abnormally elevated urinary calcium, which can result from high doses of supplemental calcium, increases the risk of developing calcium-containing kidney stones.[53] High calcium intake has also been linked with increased risk of prostate cancer, but it has been difficult to separate the potential effect of dairy products from that of calcium.

Excessive calcium intake can cause constipation and may interfere with the absorption of other minerals such as iron, zinc, magnesium, and phosphorus. Although calcium supplements inhibit iron absorption, there is no evidence that the long-term use of calcium supplements with meals affects iron status.[58] High intakes of calcium from supplements have also been found to reduce zinc absorption and thereby increase the amount of zinc needed

in the diet.[59] There is no evidence of depletion of phosphorus or magnesium associated with calcium intake.

The UL for calcium in young adults ages 19 to 50 is 2500 mg/day. In older adults the UL is lower, only 2000 mg/day, based on the occurrence of kidney stones in older age groups.[53]

11.4 Phosphorus (P)

LEARNING OBJECTIVES

- Describe the functions of phosphorus in the body.
- Plan a diet that meets the recommended intakes for calcium and phosphorus.

Phosphorus makes up about 1% of the adult body by weight, and 85% of this is found in bones and teeth.[50] The phosphorus in soft tissues has both structural and regulatory roles. In nature, phosphorus is most often found in combination with oxygen as phosphate (Figure 11.14).

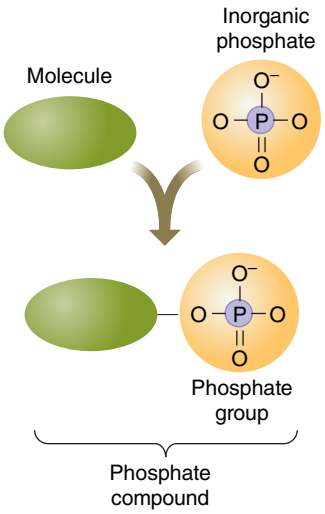


FIGURE 11.14 Phosphate
When inorganic phosphate (phosphorus combined with oxygen) joins with another molecule, it is called a phosphate group.

Phosphorus in the Diet

Phosphorus is more widely distributed in the diet than calcium. Like calcium, it is found in dairy products such as milk, yogurt, and cheese, but meat, cereals, bran, eggs, nuts, and fish are also good sources (Figure 11.15). Food additives used in baked goods, cheese, processed meats, and soft drinks also contribute to dietary phosphorus.

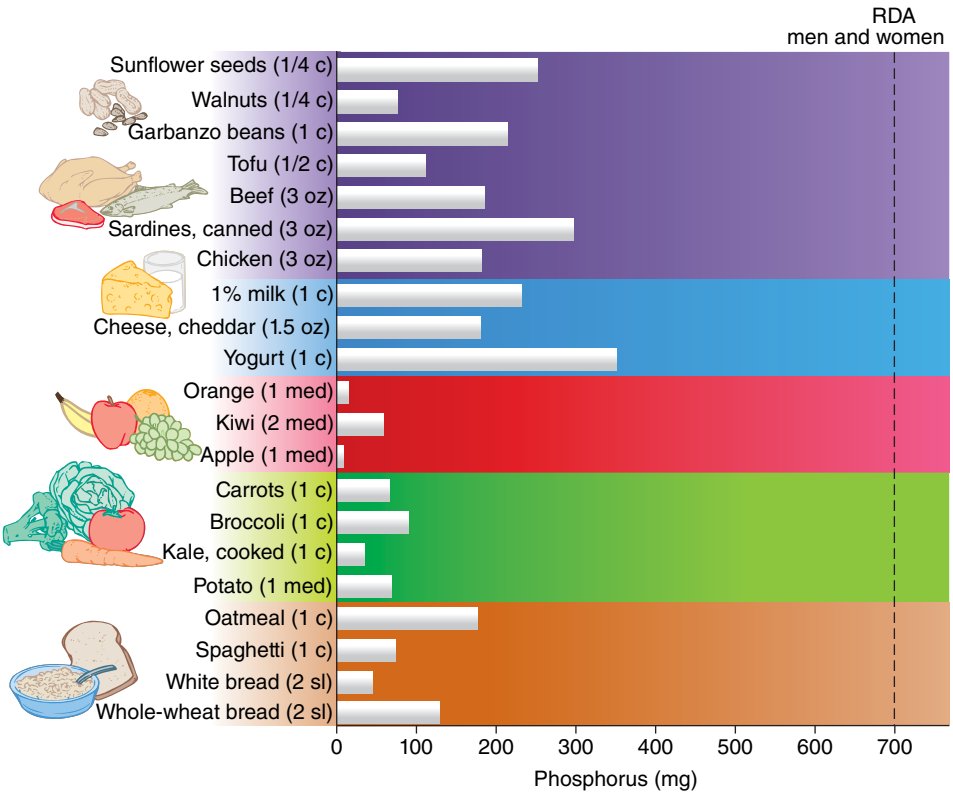


FIGURE 11.15 Phosphorus content of MyPlate food groups
Adults can obtain their RDA for phosphorus (dashed line) by consuming foods in all the food groups.

Phosphorus in the Digestive Tract

Phosphorus is more readily absorbed than calcium. About 60 to 70% is absorbed from a typical diet. There is no evidence that the efficiency of absorption is affected by the amount in the diet. Vitamin D does aid phosphorus absorption via an active mechanism, but most absorption occurs by a mechanism that does not depend on vitamin D. Therefore, when vitamin D is deficient, phosphorus can still be absorbed, but its absorption is reduced.

How Phosphorus Functions in the Body

Phosphorus is an important component of a number of molecules with structural or regulatory roles. Phosphorus, along with calcium, forms hydroxyapatite crystals that provide rigidity to bones. Phosphorus is a component of the water-soluble head of phospholipid molecules, which form the structure of cell membranes (see Chapter 5). Phosphorus is a major constituent of the genetic material DNA and RNA, and it is essential for energy metabolism because the high-energy bonds of ATP are formed between phosphate groups (Figure 11.16). Phosphorus is also a component of other high-energy compounds, including creatine phosphate, which provides energy to exercising muscles. Phosphorus-containing molecules are important in relaying signals to the interior of cells to mediate hormone action and perform other metabolic activities. Phosphorus is involved in regulating enzyme activity because the addition of a phosphate group can activate or deactivate certain enzymes. It is also part of the phosphate buffer system that helps regulate the pH in the cytosol of all cells so that chemical reactions can proceed normally.

Blood levels of phosphorus are not as strictly controlled as those of calcium, but levels are maintained in a ratio with calcium that allows bone mineralization. When blood levels of phosphorus are low, the active form of vitamin D is synthesized. This increases the absorption of both phosphorus and calcium from the intestine and increases their release from bone. When phosphorus intake is high, more is lost in the urine, so plasma levels rise only slightly. A rise in serum phosphorus indirectly stimulates PTH release, causing phosphorus excretion and calcium retention by the kidney as well as calcium release from bone. When PTH is not secreted, as when calcium levels rise, phosphorus is retained by the kidney and calcium is excreted.

Phosphorus Deficiency

Phosphorus deficiency can lead to bone loss, weakness, and loss of appetite. Deficiency is rare in healthy people because phosphorus is so widely distributed in foods. Most people in the United States easily meet their needs; the average daily intake is about 1400 mg for adult men and 1000 mg for adult women.[50] Marginal phosphorus deficiencies are most common in premature

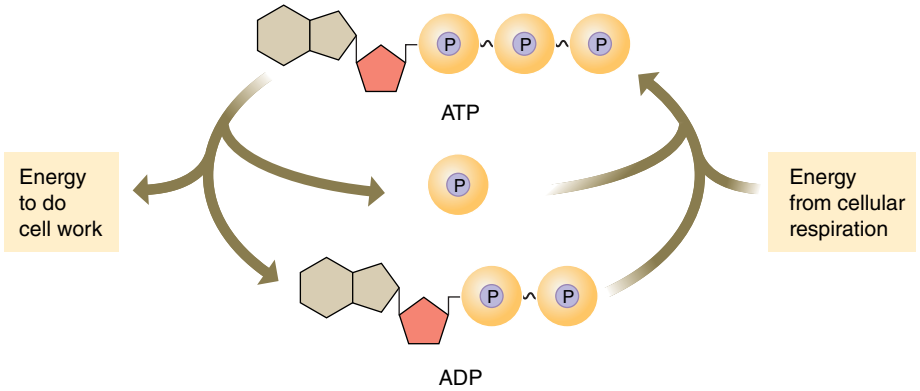


FIGURE 11.16 Phosphorus and ATP
Breaking the high-energy bond between the second and third phosphate groups of ATP releases energy for cellular work. The ADP (adenosine diphosphate) that is formed can be converted back to ATP by using the energy trapped by the electron transport chain of cellular respiration to add a phosphate group.

infants, older adults, and people with alcoholism. Marginal phosphorus status may also be caused by losses due to chronic diarrhea and overuse of aluminum-containing antacids, which prevent phosphorus absorption.

Recommended Phosphorus Intake

The RDA for phosphorus is set at 700 mg/day for men and women 19 to 50 years of age.[50] This is the amount needed to maintain normal blood phosphorus levels. Because neither absorption nor urinary losses change significantly with age, the RDA is the same for older adults.

For growing children and adolescents, the RDA is based on the phosphorus intake necessary to meet the needs for bone and soft-tissue growth. There is no evidence that phosphorus requirements are increased during pregnancy; intestinal absorption increases by about 10%, which is sufficient to provide the additional phosphorus needed by the mother and fetus. The RDA is not increased during lactation because the phosphorus in milk is provided by an increase in bone resorption and a decrease in urinary excretion that are independent of dietary intake of either phosphorus or calcium.

Excessive Phosphorus

Toxicity from high phosphorus intake is rare in healthy adults, but excessive intakes can lead to bone resorption. Typical intake in the United States is above recommendations. One reason is the increased use of phosphorus-containing food additives. This has led to concern about its impact on bone health. High phosphorus intake has been found to increase bone resorption, but this can be prevented by adequate calcium intake.[60] Levels of phosphorus intake typical in the United States are therefore a concern, because a significant portion of the population does not consume adequate amounts of calcium.[61] Based on the upper level of normal serum phosphate, a UL for phosphorus of 4 g/day has been set for adults ages 19 to 70 years.[50]

11.5 Magnesium (Mg)

LEARNING OBJECTIVES

- Name three foods that are good sources of magnesium.
- Describe the functions of magnesium in the body.

Magnesium is a mineral that affects the metabolism of calcium, sodium, and potassium. The adult human body contains approximately 25 g of magnesium.

Magnesium in the Diet

Magnesium is found in leafy greens such as spinach and kale because it is a component of chlorophyll. Nuts, seeds, bananas, and the germ and bran of whole grains are also good sources (Figure 11.17). Processed foods are generally poor sources. For example, removing the bran and germ of the wheat kernel reduces the magnesium content of a cup of white flour to only 28 mg, compared with the 166 mg in a cup of whole-wheat flour. In areas with hard water, the water supply may provide a significant amount of magnesium.

Magnesium in the Digestive Tract

About 50% of the magnesium in the diet is absorbed, and the percentage decreases as intake increases. The active form of vitamin D can enhance magnesium absorption to a small extent, and the presence of phytate decreases absorption. As calcium in the diet increases, the absorption of magnesium decreases, so the use of calcium supplements can reduce the absorption of magnesium.

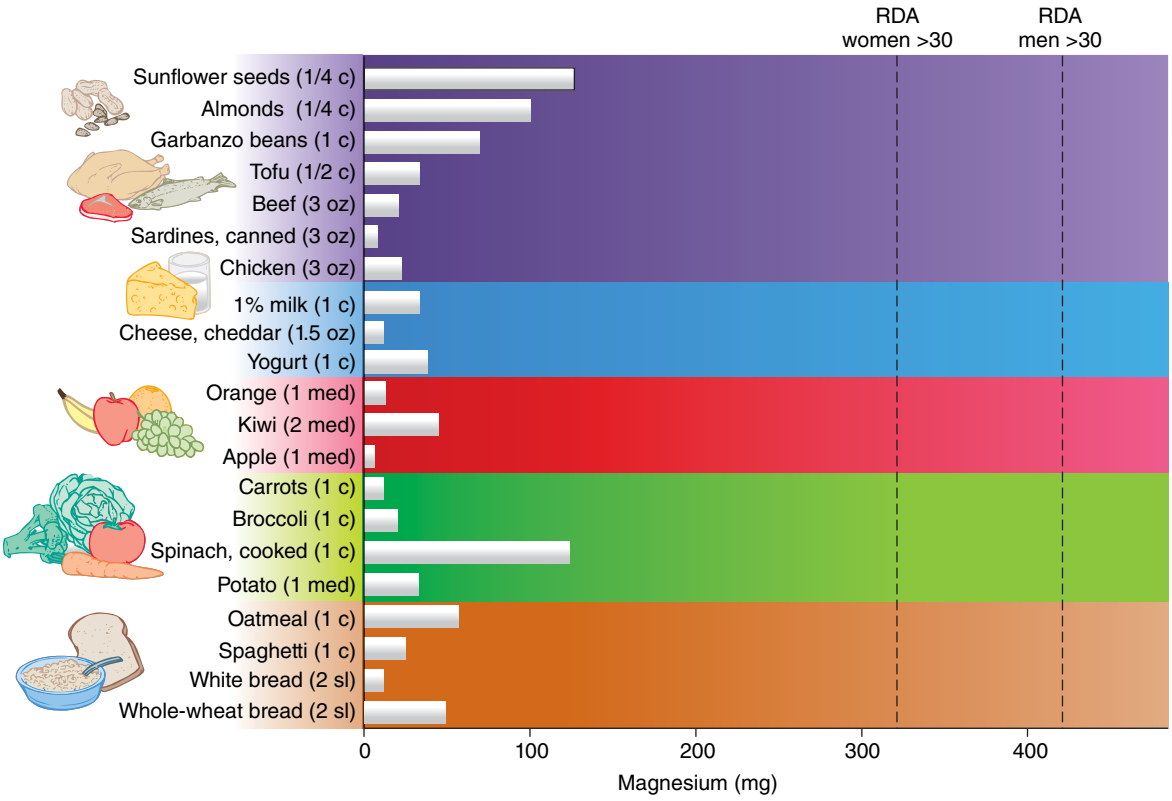


FIGURE 11.17 Magnesium content of MyPlate food groups
Magnesium is found in nuts, seeds, legumes, and leafy greens; the dashed lines represent the RDAs for adult women and men over age 30.

How Magnesium Functions in the Body

About 50 to 60% of the magnesium in the body is in bone, where it is essential to maintain healthy bone structure. Most of the remaining body magnesium is present inside cells, where it is the second most abundant positively charged intracellular ion (after potassium). Magnesium is associated with the negative charge on phosphate-containing molecules such as ATP (Figure 11.18). Magnesium is also involved in regulating calcium homeostasis and is needed for the action of vitamin D and many hormones, including PTH.[62]

Metabolism

Magnesium is a cofactor for over 300 enzymes. It is necessary for the generation of ATP from carbohydrate, fat, and protein. In some of these reactions, it is involved indirectly as a stabilizer of ATP and, in others, directly as an enzyme activator. Magnesium is needed for the activity of the sodium-potassium pump, which is responsible for active transport of sodium and potassium across membranes. It is therefore essential for maintenance of electrical potentials across cell membranes and proper functioning of the nerves and muscles, including those in the heart. It is important for DNA and RNA synthesis and for almost every step in protein synthesis. Therefore, magnesium is particularly important for dividing growing cells.

The kidneys closely regulate blood levels of magnesium. When magnesium intake is low, excretion in the urine is decreased. As intake increases, urinary excretion increases to maintain normal blood levels. This efficient regulation permits homeostasis over a wide range of dietary intakes.

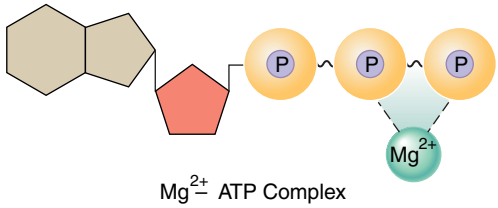


FIGURE 11.18 Magnesium stabilizes ATP
The magnesium ion (Mg^{2+}) stabilizes ATP structure by forming a magnesium–ATP complex. It is therefore important for all reactions that use or generate ATP.

Magnesium Deficiency

Overt magnesium deficiency is rare in the general population. It does occur in those with alcoholism, malnutrition, kidney disease, and gastrointestinal disease. Certain medications can also lead to low blood levels of magnesium. Diuretics can contribute to magnesium deficiency by increasing magnesium loss in the urine. Proton pump inhibitors, which are taken to treat GERD,

may cause low blood magnesium by interfering with magnesium absorption.[63] Deficiency symptoms include nausea, muscle weakness and cramping, irritability, mental derangement, and changes in blood pressure and heartbeat. Low blood magnesium levels affect levels of blood calcium and potassium; therefore, some of these symptoms may be due to alterations in the levels of these other minerals.

Although symptomatic magnesium deficiency is rare, the typical intake of magnesium in the United States is below the RDA. Low intakes of magnesium have been associated with a number of chronic diseases, including cardiovascular disease, type 2 diabetes, and osteoporosis.[64] As discussed in Chapter 10, dietary patterns that are high in magnesium are associated with lower blood pressure. The risk of other types of cardiovascular disease is also lower for people with adequate magnesium intake than for those with less magnesium in their diet.

Recommended Magnesium Intake

The RDA for magnesium is 400 mg/day for young men and 310 mg/day for young women.[50] This is based on the maintenance of total body magnesium balance over time. The RDA is slightly higher for men and women over age 30: 420 and 320 mg/day, respectively. A cup of whole-grain breakfast cereal, spinach, or legumes contains about 100 mg of magnesium.

The magnesium requirement for pregnancy is increased by 40 mg/day to account for the addition of lean body mass. No increase is recommended for lactation because magnesium is released when bone is resorbed and urinary excretion is decreased. An AI is set for infants based on the magnesium content of human milk.

Magnesium Toxicity and Supplements

No adverse effects have been observed from ingestion of magnesium from food, but toxicity may occur from concentrated sources such as magnesium-containing drugs and supplements. Toxicity has been reported in elderly patients with impaired kidney function who frequently use magnesium-containing laxatives and antacids such as milk of magnesia. Magnesium toxicity is characterized by nausea, vomiting, low blood pressure, and cardiovascular changes. The UL for adults and adolescents over 9 years of age is 350 mg from nonfood sources of magnesium.

11.6 Sulfur (S)

LEARNING OBJECTIVES

- Name sources of sulfur in the diet.
- Discuss the role of sulfur in the body.

Dietary sulfur is found in organic molecules such as the sulfur-containing amino acids in proteins and the sulfur-containing vitamins. It is also found in some inorganic food preservatives such as sulfur dioxide, sodium sulfite, and sodium and potassium bisulfite, which are used as antioxidants.

In the body, the sulfur-containing amino acids methionine and cysteine are needed for protein synthesis. Cysteine is also part of the compound glutathione, which is important in detoxifying drugs and protecting cells from oxidative damage. The vitamins thiamin and biotin, essential for ATP production, contain sulfur. Sulfur-containing ions are important in regulating acid–base balance.

There is no recommended intake for sulfur, and no deficiencies are known when protein needs are met. Table 11.2 provides a summary of sources, recommended intakes, functions, deficiencies, and toxicities of calcium, phosphorus, magnesium, and sulfur.

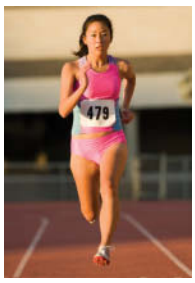
TABLE 11.2 A Summary of Calcium, Phosphorus, Magnesium, and Sulfur (All Values Are RDAs Unless Otherwise Noted)

Mineral	Sources	Recommended intake for adults	Major functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
Calcium	Dairy products, fish consumed with bones, leafy green vegetables, fortified foods	1000–1200 mg/day	Bone and tooth structure, nerve transmission, muscle contraction, blood clotting, blood pressure regulation, hormone secretion	Increased risk of osteoporosis	Postmenopausal women; older adults; those who consume a vegan diet, are lactose intolerant, or have kidney disease	Elevated blood calcium, kidney stones, and other problems in susceptible individuals	2000–2500 mg/day from food, fortified food, and supplements
Phosphorus	Meat, dairy, cereals, baked goods	700 mg/day	Structure of bones and teeth, membranes, ATP, and DNA; acid–base balance	Bone loss, weakness, lack of appetite	Premature infants, people with alcoholism, older adults	None likely	4000 mg/day
Magnesium	Greens, whole grains, legumes, nuts, seeds	310–420 mg/day	Bone structure, ATP stabilization, enzyme activity, nerve and muscle function	Nausea, vomiting, weakness, muscle pain, heart changes	People with alcoholism, individuals with kidney or gastrointestinal disease	Nausea, vomiting, low blood pressure	350 mg/day from nonfood sources
Sulfur	Protein foods, preservatives	None specified	Part of some amino acids and vitamins, acid–base balance	None when protein needs are met	None	None likely	ND

Note: UL, Tolerable Upper Intake Level; ND, not determined due to insufficient data.

OUTCOME

PhotoDisc, Inc./Getty Images



Blend Images/Getty Images, Inc.

Mika's low bone density is due to a number of factors. She doesn't consume enough calcium to maximize her bone density, and she has stopped menstruating, a condition called amenorrhea. Her energy-restricted diet combined with her high level of exercise contributes to a low level of body fat and low levels of estrogen, leading to amenorrhea. Just as low estrogen contributes to bone loss in postmenopausal women, it has a similar impact in young women. The combination of low energy intake, amenorrhea, and low bone density is referred to as the female athlete triad (see Focus on Eating Disorders and Chapter 13). To prevent further bone loss and hopefully improve her bone density, Mika needs to make some lifestyle changes. The goals for Mika's recovery plan are to increase her caloric intake and improve her diet by choosing a diet that meets MyPlate recommendations and cut back on her training so she can gain weight and restore her menstrual cycle. With the help of behavioral and dietary counseling, after about six months she is able to bring her BMI back into the healthy range. **She is now menstruating and is running three to four days a week, rather than six days a week.**

SUMMARY

11.1 What Are Minerals?

- Minerals are elements needed by the body to regulate chemical reactions and provide structure. They are divided into major minerals and trace minerals based on the amount required in the diet and present in the body. They are found in both plant and animal foods. Minerals are added to some foods through fortification and get into others as a result of contamination. Dietary supplements are also a source of minerals.
- Deficiencies of certain minerals are world health problems. Mineral bioavailability is affected by body needs as well as interactions with other minerals, vitamins, and dietary components such as fiber, phytates, oxylates, and tannins. Minerals contribute to the body's structure and help regulate body processes, often as cofactors.

11.2 Minerals, Osteoporosis, and Bone Health

- Bone consists of a protein matrix hardened by mineral deposits. It is a living tissue that is constantly being broken down and re-formed in a process known as bone remodeling. Early in life, bone formation occurs more rapidly than bone breakdown to allow bone growth and an increase in bone mass. Loss of bone due to age and other factors increases the risk of developing osteoporosis, a condition in which loss of bone mass increases the risk of bone fractures.
- The risk of osteoporosis is related to the level of peak bone mass and the rate of bone loss. These are affected by age, gender, hormone levels, genetics, smoking, alcohol use, exercise, and diet. Peak bone mass occurs in young adulthood. With age, bone breakdown begins to outpace formation, causing a decrease in bone mass; this is accelerated in women for about 5 to 10 years surrounding menopause.
- An active lifestyle along with adequate calcium and vitamin D intake throughout life helps maintain bone mass and prevent osteoporosis. Once it has developed, osteoporosis is treated with supplemental calcium and vitamin D and medications that inhibit bone breakdown and increase calcium absorption.

11.3 Calcium (Ca)

- Sources of calcium in the American diet include dairy products, fish consumed with bones, and leafy green vegetables. Fortified foods and supplements also contribute to calcium intake.
- Sufficient calcium absorption depends on adequate levels of vitamin D. The absorption of calcium is reduced by the presence of tannins, fiber, phytates, and oxalates. Calcium absorption varies with life stage and is highest during infancy and pregnancy, when needs are greatest.
- Most of the calcium in the body is in bone. Calcium not found in bone is essential for cell communication, nerve transmission, muscle contraction, blood clotting, and blood pressure regulation. Blood levels of calcium are regulated by parathyroid hormone (PTH) and calcitonin. PTH stimulates the release of calcium from bone, decreases calcium excretion by the kidney, and activates vitamin D to increase the amount of calcium absorbed from the gastrointestinal tract and released from bone. Calcitonin blocks calcium release from bone.
- Calcium deficiency can reduce bone mass and increase the risk of osteoporosis.
- The RDA for calcium ranges from 1000 to 1200 mg/day for adults and is 1300 mg/day in adolescents and pregnant and lactating women.
- Too much calcium can contribute to the formation of kidney stones, raise blood calcium levels, and interfere with the absorption of other minerals.

11.4 Phosphorus (P)

- Phosphorus is more widely distributed in the diet than calcium. It is found in dairy products such as milk, yogurt, and cheese; meat, cereals, bran, eggs, nuts, and fish are also good sources. Food additives used in baked goods, cheese, processed meats, and soft drinks also contribute to dietary phosphorus.
- About 60 to 70% of the phosphorus in a typical diet is absorbed. Vitamin D aids phosphorus absorption via an active mechanism, but most absorption occurs by a mechanism that does not depend on vitamin D.
- Most of the phosphorus in the body is found in bones and teeth. In addition to its structural role in these tissues, phosphorus is an essential component of phospholipids, ATP, and DNA and RNA. Phosphorus is also part of a buffer system that helps prevent changes in pH.
- Phosphorus deficiency is rare in healthy people because phosphorus is so widely distributed in foods. Deficiency can lead to bone loss, weakness, and loss of appetite.
- The RDA for adults is 700 mg of phosphorus per day.
- Symptoms related to high phosphorus intake are rare in healthy adults, but excessive intakes can lead to bone resorption. The levels of phosphorus intake typical in the United States are not believed to affect bone health as long as calcium intake is adequate.

11.5 Magnesium (Mg)

- Magnesium is found in leafy greens such as spinach and kale because it is a component of chlorophyll. Nuts, seeds, bananas, and the germ and bran of whole grains are also good sources.
- About half of the magnesium in the diet is absorbed, and the percentage decreases as intake increases. The active form of vitamin D can enhance magnesium absorption and the presence of phytates decreases absorption.
- Magnesium is important for bone health, and it is needed as a cofactor for numerous reactions throughout the body. In reactions involved in energy metabolism it acts as an enzyme activator and stabilizer of ATP. It is also needed to maintain membrane potentials; thus it is essential for nerve and muscle conductivity. Homeostasis is regulated by the kidney.
- Magnesium deficiency is rare in the general population, but intakes generally do not meet recommendations. Deficiency does occur in those with alcoholism, malnutrition, kidney disease, and gastrointestinal disease. Symptoms include nausea, muscle

weakness and cramping, irritability, mental derangement, and changes in blood pressure and heartbeat.

- The RDA for magnesium is 400 mg/day for young men and 310 mg/day for young women.
- No adverse effects have been observed from ingestion of magnesium from food, but toxicity may occur from magnesium-containing drugs and supplements.

11.6 Sulfur (S)

- Sulfur is in the diet as preformed organic molecules such as the amino acids methionine and cysteine, which are needed to synthesize proteins and glutathione, and the vitamins thiamin and biotin, needed for energy metabolism. Sulfur is also part of a buffer system that regulates acid–base balance. A dietary deficiency is unknown in the absence of protein malnutrition.

CHAPTER OUTLINE

12.1 Trace Minerals in Our Diet

12.2 Iron (Fe) Sources and Functions
- Iron in the Diet
- Iron in the Digestive Tract
- How Iron Homeostasis Is Regulated
- How Iron Functions in the Body

12.3 Meeting Iron Needs
- Iron Deficiency
- Recommended Iron Intake
- Iron Toxicity
- How to Get Enough Iron

12.4 Zinc (Zn)
- Zinc in the Diet
- Zinc in the Digestive Tract
- How Zinc Functions in the Body
- Zinc Deficiency
- Recommended Zinc Intake
- Zinc Toxicity
- Zinc Supplements

12.5 Copper (Cu)
- Copper in the Diet
- Copper in the Digestive Tract
- How Copper Functions in the Body
- Copper Deficiency
- Recommended Copper Intake
- Copper Toxicity

12.6 Manganese (Mn)
- How Manganese Functions in the Body
- Manganese Deficiency and Toxicity
- Recommended Manganese Intake

12.7 Selenium (Se)
- Selenium in the Diet
- How Selenium Functions in the Body
- Selenium Deficiency
- Recommended Selenium Intake
- Selenium Toxicity and Supplements

12.8 Iodine (I)
- Iodine in the Diet
- How Iodine Functions in the Body
- Iodine Deficiency
- Recommended Iodine Intake
- Iodine Toxicity

12.9 Chromium (Cr)
- Chromium in the Diet
- How Chromium Functions in the Body
- Chromium Deficiency
- Recommended Chromium Intake
- Chromium Supplements and Toxicity

12.10 Fluoride (F)
- Fluoride in the Diet
- How Fluoride Functions in the Body
- Fluoride Deficiency
- Recommended Fluoride Intake
- Fluoride Toxicity

12.11 Molybdenum (Mo)

12.12 Other Trace Elements

(©iStockphoto)

© amana images Inc./Alamy Limited

The Trace Minerals

12

CASE STUDY

Nissi is a 12-year-old girl who lives in a small village in India. She has been feeling tired and has noticed a lump in her neck that seems to be getting bigger. Her mother takes her to the local clinic, where the doctor determines that her lethargy and the swelling in her neck, which is called a goiter, are caused by an iodine deficiency. He gives Nissi an injection of iodine and explains that, if left untreated, Nissi's symptoms would have continued to worsen.

How could an apparently healthy young girl have a nutritional deficiency? Her diet consists almost entirely of homegrown grains, pulses (seeds, beans, and lentils), and vegetables. These locally grown foods, however, are deficient in iodine because the Ganges River Valley has flooded repeatedly over the centuries washing the iodine out of the soil. So a diet based solely on local foods does not provide enough of this essential mineral to meet dietary needs. Iodine deficiency is a problem not only for Nissi, but also for others in her village. Goiter is common, and young women who are deficient in iodine during pregnancy are at risk of giving birth to babies with developmental abnormalities.

One way to prevent iodine deficiency in an otherwise healthy diet is to include foods that are higher in iodine. However, this approach is not practical for Nissi because all of the food grown in the region—and thus her entire diet—is deficient in iodine. **A different approach must be used to ensure that Nissi's family and others in her village obtain adequate iodine.**

PhotosIndia.com/Getty Images, Inc.

12.1 Trace Minerals in Our Diet

LEARNING OBJECTIVES

- Discuss why it can be difficult to study the requirements for and functions of many of the trace minerals.
- Explain why bioavailability is particularly important in meeting trace mineral needs.

The trace minerals—iron, zinc, copper, manganese, selenium, iodine, chromium, fluoride, and molybdenum, and several others—are required in the diet in an amount of 100 mg or less per day or present in the body in an amount of 0.01% or less of body weight. Like the major minerals, they serve a variety of essential structural and regulatory roles. Iodine is needed to make thyroid hormones, iron is needed to carry oxygen to body cells, and fluoride is needed for strong teeth. Selenium, copper, zinc, iron, and manganese are each cofactors for antioxidant enzyme systems that protect the body from oxidative damage.

The small amounts in which the trace minerals are found in the diet and in the body make them difficult to study. Usually, nutrient needs are evaluated by feeding a diet devoid of that nutrient. However, with some trace minerals, needs are so small that contamination from the environment and minerals already present in the body can obscure experimental results. Bioavailability is also more of a concern with trace minerals because such small amounts are present in the diet. Phytates, tannins, oxalates, and fiber can bind minerals, reducing their absorption. For example, when the diet is based on unleavened grains, the phytate content may be high enough to decrease zinc absorption and cause a zinc deficiency. The interactions among the minerals that can affect their absorption and utilization can also have an impact on trace mineral status. For example, a deficiency of copper can decrease available iron by reducing the amount of iron that can bind to iron transport proteins in the blood.

Determining the amounts of trace minerals that foods contribute to the diet is difficult and is compromised by the fact that the amounts of some are affected by the soil content where the food is grown or produced. For example, a loaf of bread made from wheat grown in one location may supply a different amount of selenium than does a loaf made from wheat grown elsewhere. When modern transportation systems make foods produced in many locations available, this variation is unlikely to affect mineral status. In countries where the diet consists predominantly of locally grown foods, individual trace element deficiencies and excesses are more likely.

12.2 Iron (Fe) Sources and Functions

LEARNING OBJECTIVES

- List some dietary sources of heme and nonheme iron.
- Explain how the amount of iron in the body is regulated.
- Describe the primary functions of iron.

hemoglobin An iron-containing protein in red blood cells that binds oxygen and transports it through the bloodstream to cells.

heme iron A readily absorbed form of iron found in animal products that is chemically associated with proteins such as hemoglobin and myoglobin.

Iron was identified as a major constituent of blood in the 18th century. By 1832, iron tablets were being used to treat young women in whom "coloring matter" was lacking in the blood. Today we know that the red color in blood is due to the iron-containing protein **hemoglobin** and that a deficiency of iron decreases hemoglobin production. Even though iron is one of the best understood of the trace minerals, iron deficiency remains the most common nutritional deficiency worldwide and is a problem among certain population groups in the United States.[1,2]

Iron in the Diet

Iron in the diet comes from both plant and animal sources (Figure 12.1). Much of the iron in animal products is **heme iron**—iron that is part of a chemical complex called a *heme group*,

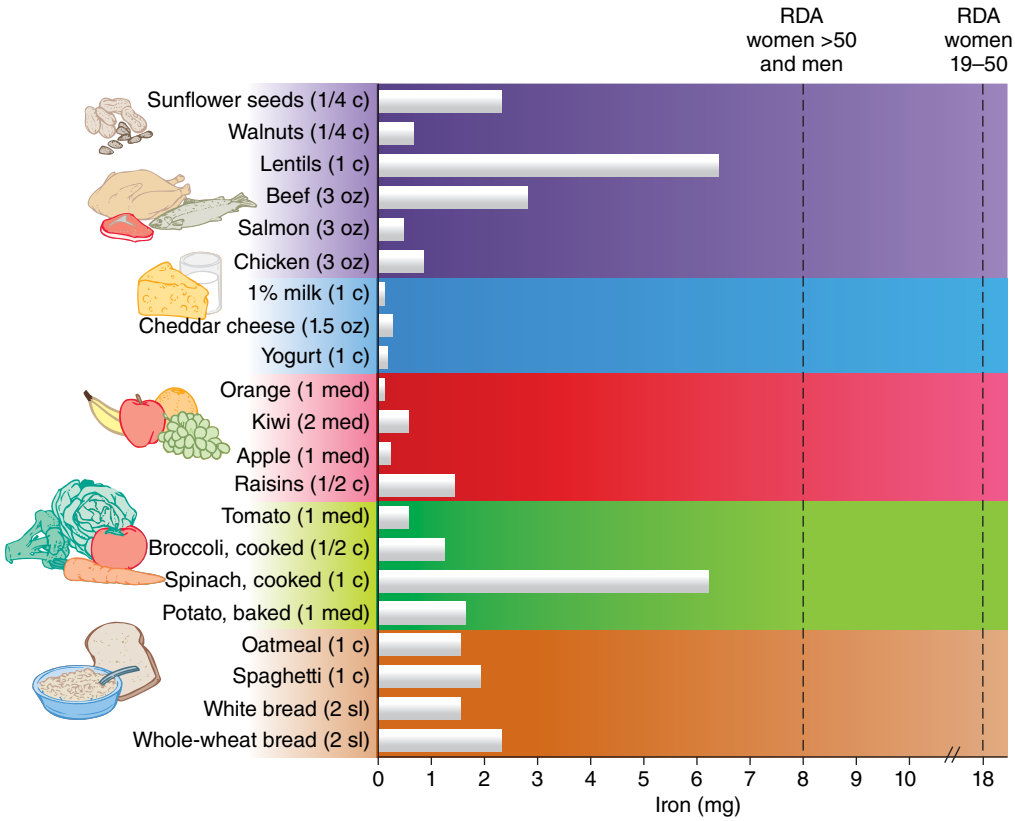


FIGURE 12.1 Iron content of MyPlate food groups
Both plant and animal foods are good sources of iron. Meat, poultry, and fish provide both heme and nonheme iron. Plant foods contain only nonheme iron. The dashed lines represent the RDAs for men and postmenopausal women and for women of childbearing age.

found in proteins such as hemoglobin in blood and **myoglobin** in muscle (Figure 12.2). Meat, poultry, and fish are good sources of heme iron. Heme iron accounts for about 10 to 15% of the dietary iron in meat-eating populations.[3]

Leafy green vegetables, legumes, and whole and enriched grains are good sources of **nonheme iron**. Another source of nonheme iron in the diet is iron cooking utensils, from which iron leaches into food. Leaching is enhanced by acidic foods. For example, 3 oz of spaghetti sauce cooked in a glass pan contains about 0.6 mg of iron, but the same sauce cooked in an iron skillet contains about 5.7 mg, depending on how long it is cooked.

myoglobin An iron-containing protein in muscle cells that binds oxygen.

nonheme iron A poorly absorbed form of iron found in both plant and animal foods that is not part of the iron complex found in hemoglobin and myoglobin.

Iron in the Digestive Tract

Iron from the diet is absorbed into the intestinal mucosal cells. The amount absorbed depends on whether the iron is heme or nonheme iron as well as on the presence of dietary components that enhance or inhibit iron absorption.

Heme iron is absorbed more efficiently than nonheme iron and is not significantly affected by most dietary factors that affect nonheme iron absorption. Bioavailability of iron from mixed diets that include meat and seafood is about 14 to 18%, compared to only 5 to 12% from vegetarian diets that contain only nonheme iron sources.[4] When foods containing heme proteins are consumed, the iron-containing heme group is released from the proteins by protein-digesting enzymes. The heme binds to receptors on the surface of mucosal cells, allowing it to enter the cells, where the iron is released from the heme group.

When foods containing nonheme iron are consumed, stomach acid helps convert the ferric form (Fe^{3+}) of iron to the ferrous form (Fe^{2+}). The ferrous form of iron remains more soluble when it enters the intestine and therefore is absorbed into the mucosal cells more readily. When foods containing nonheme iron are consumed with foods containing acids, such as ascorbic acid (vitamin C), citric acid, or lactic acid, iron absorption is enhanced because the acid helps to keep iron in the ferrous (Fe^{2+}) form. The best studied of these acids is vitamin C,

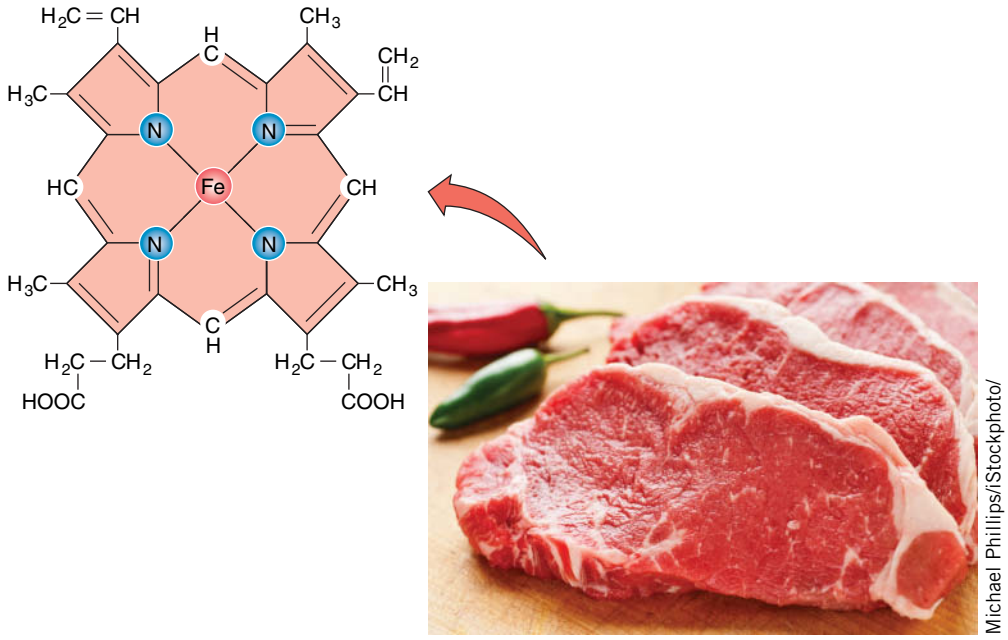


FIGURE 12.2 Heme iron
The myoglobin in red meat provides heme iron and gives the meat its red color. A heme group contains four 5-membered nitrogen-containing rings that form a cage around a central iron ion. In hemoglobin and myoglobin the iron ion is in the Fe^{2+} state.

which enhances nonheme iron absorption both by keeping the iron in its more absorbable form and by forming a complex with iron that remains soluble and more bioavailable.[3] Vitamin C can enhance nonheme iron absorption up to sixfold. Another dietary component that increases the absorption of nonheme iron is meat such as beef, fish, or poultry. For example, a small amount of ground beef in a pot of chili will enhance the body's absorption of nonheme iron from the beans.

Dietary factors that interfere with the absorption of nonheme iron include fiber, phytates found in cereals, tannins found in tea, and oxalates found in some leafy greens such as spinach.[3] These prevent absorption by binding iron in the gastrointestinal tract. They are not consumed in large enough quantities in the United States to cause an iron deficiency. However, these components do contribute to iron deficiency in parts of the developing world where they are consumed in larger amounts and the diet is low in heme iron and in foods and nutrients that enhance nonheme iron absorption.[5] The presence of other minerals may also interfere with iron absorption. For instance, large amounts of calcium consumed in the same meal with iron can decrease iron absorption. However, over the long term, the effect of calcium on iron absorption from a varied diet that includes other inhibitors and enhancers of iron absorption is minimal.[3]

How Iron Homeostasis Is Regulated

Iron is essential for life, but in excess it is toxic. To protect against the toxic effects of iron, the body regulates the amount that enters the blood from the mucosal cells of the gastrointestinal tract and has evolved ways to safely transport and store it.

The amount of iron in the body is controlled primarily at the intestine (Figure 12.3). Iron that has entered the mucosal cells of the small intestine can be bound to the iron storage protein **ferritin** or transferred into the blood and picked up by the iron transport protein **transferrin**. Iron that remains bound to ferritin is excreted in the feces when mucosal cells die and are sloughed off into the intestinal lumen (see Figure 12.3). Iron that is picked up by transferrin is transported in the blood to the liver, bones, and other body tissues. Transferrin picks up iron from the intestinal mucosal cells in the small intestine as well as iron released from the breakdown of hemoglobin. Before iron can bind transferrin, it must be converted to the ferric (Fe^{3+}) form. In the intestine, this is accomplished by the action of a copper-containing protein located in the mucosal cell membrane.[6]

ferritin The major iron storage protein.

transferrin An iron transport protein in the blood.

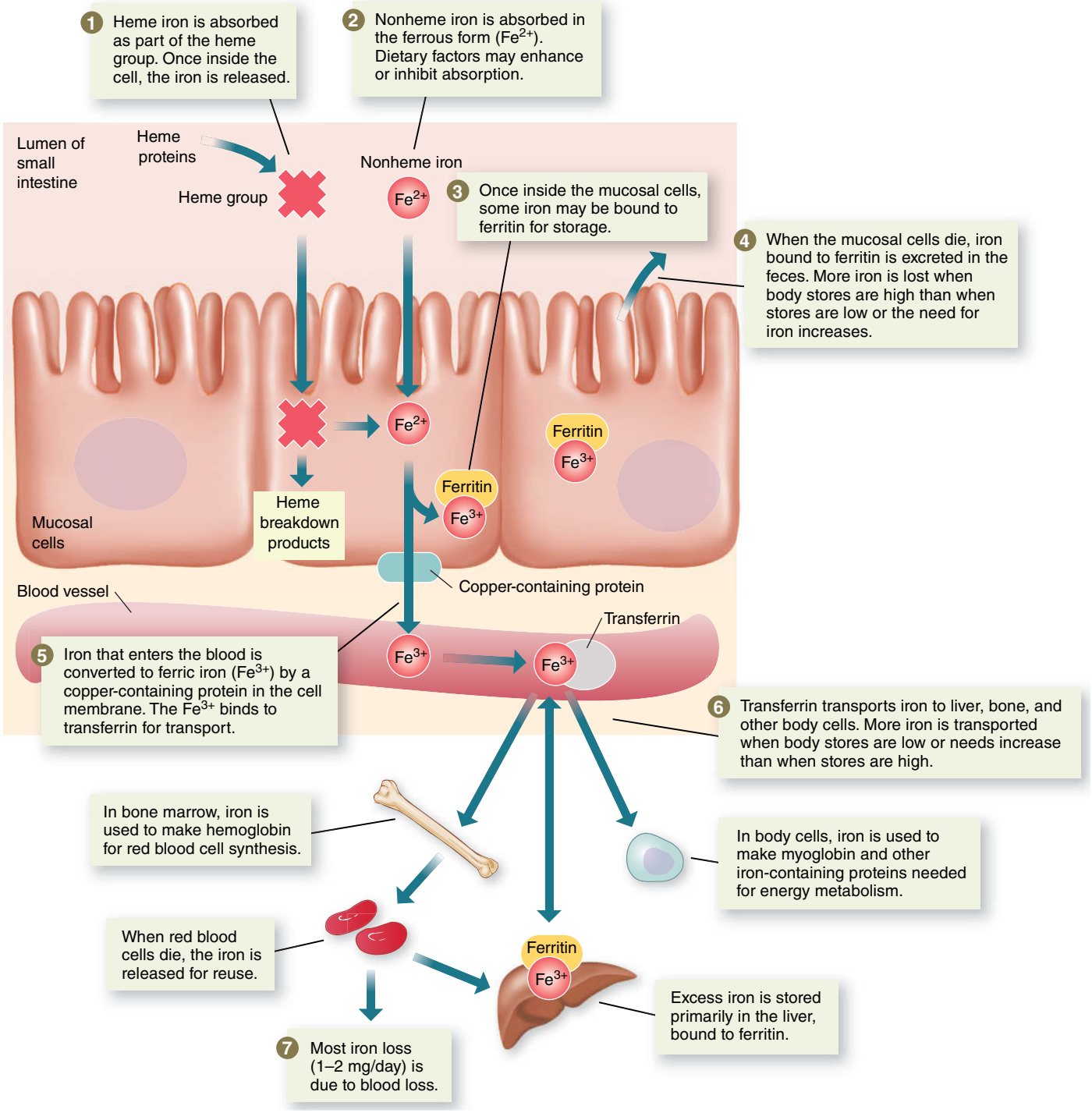


FIGURE 12.3 Iron absorption and transport
The amount of iron available to the body depends on both the amount absorbed into the mucosal cells of the small intestine and the amount transported to the rest of the body. The amount of iron that leaves the mucosal cells for transport to liver, bone, and other tissues is carefully regulated to maintain iron homeostasis. Iron loss is due primarily to blood loss.

The amount of iron transported from the mucosal cells to the rest of the body depends on body iron needs. The primary regulator of iron homeostasis is a peptide hormone called *hepcidin* released by the liver.[7] When body iron levels are low, little hepcidin is released, allowing intestinal mucosal cells to transfer iron into the blood, where it binds to transferrin. High levels of iron cause hepcidin release. When hepcidin concentrations increase, iron is not transported out of the mucosal cells and instead remains within the cells bound to ferritin. Hepcidin also inhibits body

cells that store iron, such as liver cells and macrophages, from releasing iron into the blood when iron levels are high.

Iron Losses and Recycling Iron uptake into the body is tightly controlled because there is no physiological mechanism for regulating iron losses. Most iron loss even in healthy individuals occurs through blood loss, including that lost during menstruation and the small amounts lost from the gastrointestinal tract. Some iron is also lost through the shedding of cells from the intestine, skin, and urinary tract. These losses total only about 1 to 2 mg of iron per day.[6] Even when red blood cells die, the iron in their hemoglobin is not lost from the body. Old red blood cells are removed from the blood by cells in the liver, spleen, and bone marrow and degraded; the recovered iron is then attached to transferrin for transport back to body tissues, including the bone, where it can be incorporated into new red blood cells (see Figure 12.3).

Iron Stores Iron that is transported from the mucosal cells into the blood in excess of immediate needs can be stored in the protein ferritin, primarily in the liver, spleen, and bone marrow. Levels of ferritin in the blood can be used to estimate iron stores. When ferritin concentrations in the liver become high, some is converted to an insoluble storage protein called **hemosiderin**. Iron can be mobilized from body stores as needed, and deficiency signs appear only after stores are depleted.

hemosiderin An insoluble iron storage compound that stores iron when the amount of iron in the body exceeds the storage capacity of ferritin.

How Iron Functions in the Body

Iron in the body is essential for the delivery of oxygen to cells. It is a component of two oxygen-carrying proteins, hemoglobin and myoglobin. Most of the iron in the body is part of hemoglobin. Hemoglobin in red blood cells transports oxygen to body cells and carries carbon dioxide away from cells for elimination by the lungs. Myoglobin is found in the muscle, where it enhances the amount of oxygen available for use in muscle contraction. Iron is also essential for ATP production as a part of several proteins involved in the citric acid cycle and the electron transport chain. Iron-containing proteins are involved in drug metabolism and immune function. Iron is also part of the enzyme catalase, which protects the cells from oxidative damage by destroying hydrogen peroxide before it can form free radicals.

12.3 Meeting Iron Needs

LEARNING OBJECTIVES

- Describe the symptoms of iron deficiency anemia and how they relate to the functions of iron.
- Discuss groups at high risk for iron deficiency and why their risk is increased.

Iron deficiency is a world health problem. It is estimated that over 30% (2 billion people) of the world's populations suffer from anemia, many due to iron deficiency.[2] In the United States, about 14% of toddlers ages 1 to 2 years and 9% of adolescent and adult women are iron deficient.[1] Among low-income and minority women and children, the incidence of iron deficiency is even greater. However, too much iron is also damaging and affects the lives and health of millions of individuals.

iron deficiency anemia An iron deficiency disease that occurs when the oxygen-carrying capacity of the blood is decreased because not enough iron is available to make adequate amounts of hemoglobin.

Iron Deficiency

When iron is deficient, hemoglobin cannot be produced. When not enough hemoglobin is available, the red blood cells that are formed are small (microcytic) and pale (hypochromic) and unable to deliver adequate oxygen to the tissues. This microcytic, hypochromic anemia is known as **iron deficiency anemia**. Anemia is the last stage of iron deficiency. Earlier stages have no symptoms because they do not affect the amount of iron in red blood cells. Iron depletion

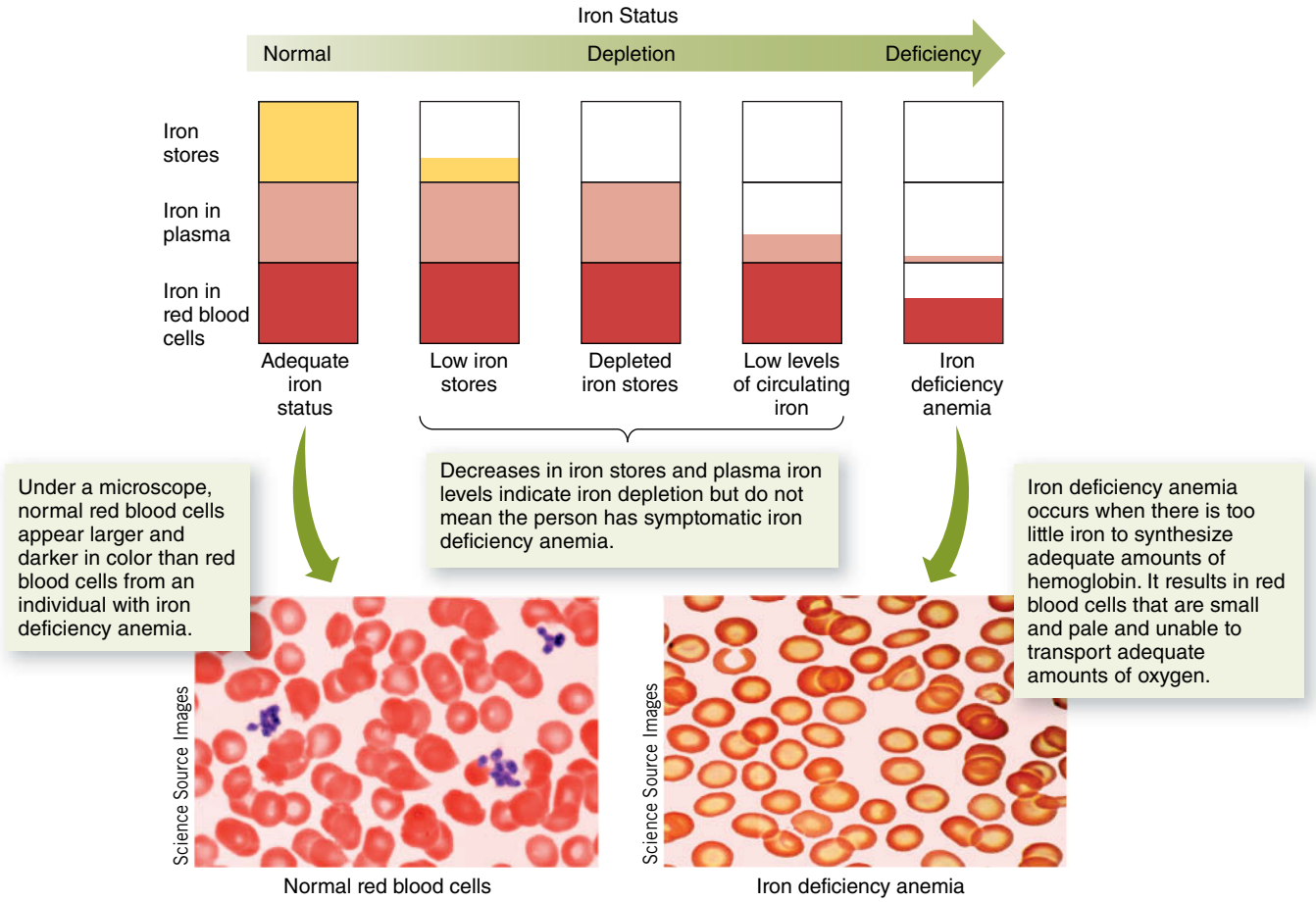


FIGURE 12.4 Progression of iron deficiency
Inadequate iron first causes a decrease in the amount of stored iron, followed by low iron levels in the plasma. It is only after plasma levels drop that there is no longer enough iron available to maintain adequate hemoglobin in red blood cells, resulting in iron deficiency anemia.

can be detected by blood tests that measure indicators of iron levels in the plasma and in body stores (Figure 12.4).

What Are the Symptoms of Iron Deficiency Anemia? The symptoms of iron deficiency anemia include fatigue, weakness, headache, decreased work capacity, an inability to maintain body temperature in a cold environment, changes in behavior, decreased resistance to infection, adverse pregnancy outcomes, impaired development in infants, and an increased risk of lead poisoning in young children. Many of these symptoms are due to the role of iron in energy metabolism and oxygen transport.

Who Is at Risk for Iron Deficiency? The risk of iron deficiency is highest among those with high iron needs such as pregnant women and growing children; those with low intakes, such as vegetarians and those who cannot afford a varied diet; and those who are actively losing iron, such as menstruating women (Figure 12.5).

Women of reproductive age are at risk for iron deficiency anemia because of iron loss due to menstruation. Menstruation is absent during pregnancy, but the need for iron is increased because of the expansion of maternal blood volume and the growth of other maternal tissues and the fetus. Iron deficiency is common among pregnant women even in industrialized countries and can lead to premature delivery and greater risk to the mother.

Iron deficiency is common in infants, children, and adolescents. In infants and children, rapid growth increases iron needs. Toddlers may also be at risk because finicky eating habits often reduce intake (see Chapter 15). In adolescent boys, rapid growth and an increase in muscle mass and blood volume increase iron needs. In adolescent girls, iron needs are increased because

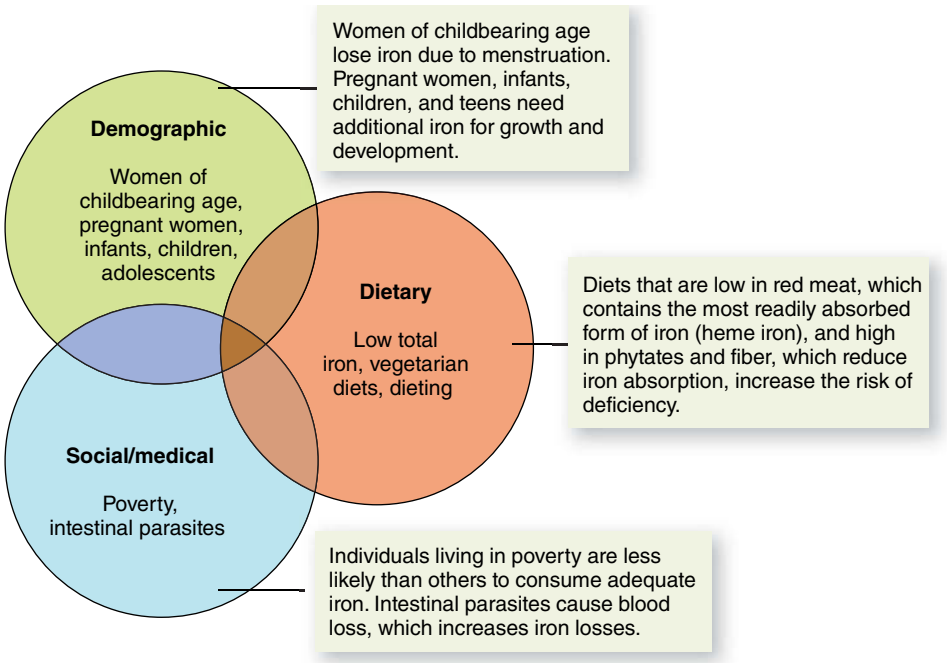


FIGURE 12.5 Factors that increase the risk of iron deficiency
The risk of iron deficiency is highest among individuals with greater iron losses, those with greater needs due to growth and development, and those who cannot obtain adequate dietary iron.

weight gain is almost as great as in boys and iron losses are increased by the onset of menstruation (see Chapter 15).

Athletes are another group at risk for iron deficiency. This may be due to a low iron intake as well as to increased losses due to prolonged training. Based on the amount lost, the EAR may be 30 to 70% higher for athletes than for the general population (see Chapter 13).[8]

Recommended Iron Intake

The RDA for iron is based on the amount needed to maintain normal function but only minimal iron stores. The RDA is set at 8 mg/day for adult men ages 19 and older and for postmenopausal women.[8] The RDA for menstruating women is increased to 18 mg/day to compensate for the iron lost in menstrual blood. Other specific recommendations have been made for each gender and life-stage group by considering the percentage of dietary iron absorbed, iron losses from the body, and conditions that increase needs, such as growth, pregnancy, and the use of oral contraceptives (see inside cover). A separate RDA category has been created for vegetarians because iron is poorly absorbed from plant sources; for example, the RDA for vegetarian women of childbearing age is 32 mg/day.

The recommended iron intake during pregnancy is increased to 27 mg/day to account for the iron deposited in the fetal and maternal tissues. The RDA during lactation is set lower than the RDA for menstruating women because little iron is lost in milk and menstruation is usually absent (see inside cover). The RDA for infants, children, and adolescents considers the additional iron needed for growth. An AI has been set for infants from newborn to 6 months based on the mean iron intake of infants principally fed human milk. Because the iron in human milk is more bioavailable than that in infant formula, it is recommended that infants who are not fed human milk or are only partially nourished with human milk be fed iron-fortified formula.

Iron Toxicity

Iron is essential for cellular metabolism, but too much can be toxic. Iron promotes the formation of free radicals and causes cell death due to excess oxidation of cellular components. Iron toxicity can be acute, resulting from ingestion of a single large dose at one time, or chronic, due to the accumulation of iron in the body over time, referred to as *iron overload*. A UL has been set at 45 mg/day from all sources.[8]

FIGURE 12.6 Iron toxicity from supplements Iron-containing products must carry this warning and should be stored out of the reach of children or other individuals who might consume them in excess.

How Acute Toxicity Affects the Body Taking a single large dose of iron can be life threatening. This acute iron poisoning can damage the intestinal lining and cause abnormalities in body pH, shock, and liver failure. Iron toxicity from supplements is one of the most common forms of poisoning among children under age 6 and is the leading cause of liver transplants in children. To protect children from accidental poisoning from iron-containing drugs and supplements, these products display a warning on the label (Figure 12.6).[9]

Why Iron Overload Is Damaging If too much iron enters the body, over time it accumulates in tissues such as the heart and liver. Iron overload can occur in people with conditions that cause abnormal red blood cell synthesis and in those with diseases requiring frequent blood transfusions, but the most common cause of chronic iron overload is **hemochromatosis**. Hemochromatosis is an inherited condition, caused by a defect in the gene for hepcidin or other proteins involved in iron uptake, that allows excess iron to enter the circulation.[10] Hemochromatosis afflicts about 1 in 250 people in Western populations and is one of the most common genetic disorders in people of northern European ancestry.[10]

hemochromatosis An inherited condition that results in increased iron absorption.

Hemochromatosis has no symptoms early in life, but in middle age nonspecific symptoms such as weight loss, fatigue, weakness, and abdominal pain typically begin. If allowed to progress, the accumulation of excess iron that occurs in hemochromatosis causes oxidative changes resulting in heart and liver damage, diabetes, certain types of cancer, and other chronic conditions. Iron deposits also darken the skin. To have these symptoms, an individual must inherit the hemochromatosis gene from both parents. Between 5 and 20% of the population inherit the gene from only a single parent; these individuals don't have these serious symptoms but do absorb iron better than people who do not have the gene at all.

The rate at which iron accumulates and leads to serious symptoms in those with hemochromatosis depends on the amount of iron consumed and other dietary factors that affect iron absorption, as well as factors that cause iron loss such as menstruation and blood donations. The public health impact of hemochromatosis is potentially significant. The availability of red meat and the prevalence of iron-fortified foods in the American diet virtually ensure that individuals with two genes for hemochromatosis will eventually accumulate damaging levels of iron. If individuals with hemochromatosis can be identified, treatment is simple: regular blood withdrawal. This will prevent the complications of iron overload, but to be effective, it must be initiated before organs are damaged.[11] Therefore, genetic screening to identify and treat young healthy individuals is essential in preventing complications.

Overconsumption of iron supplements or a diet high in absorbable iron can also increase iron stores. Although these iron stores are not high enough to cause the serious problems that occur with hemochromatosis, it has been hypothesized that people with high iron stores are at increased risk of the same diseases that occur in hemochromatosis—heart disease, diabetes, and cancer. Excess iron is hypothesized to promote heart disease by increasing the formation of oxidized LDL cholesterol, which then leads to atherosclerosis.[12,13] The reason high iron stores may

CRITICAL THINKING

Increasing Iron Intake and Uptake

Gentl and Hyers/Getty Images

BACKGROUND

Hanna is a 23-year-old graduate student. She has been feeling tired and rundown all semester. She goes to the health center where blood tests indicate that she has iron deficiency anemia. A review of her vegetarian diet is shown here.

TYPICAL DIET

FOOD	AMOUNT	IRON (mg)
Breakfast		
Grits with	1 cup	1.4
butter	1 tsp	0
Plantain	1 (3 oz)	1.8
Whole-wheat toast	1 slice	1.4
Apple juice	¾ cup	0.3
Tea with	1 cup	0
sugar	1 tsp	0
Lunch		
Apple	1 medium	0.2
Cornbread with	1 piece	0.9
butter	1 tsp	0
Yogurt, low-fat, vanilla	1 cup	0.2
Tomato, raw	1 medium	0.5
Tea with	1 cup	0
sugar	1 tsp	0
Dinner		
Rice, brown	1 cup	0.8
Peanuts	1/3 cup	1.2
Green beans, boiled	1 cup	0.8
Yams, boiled	1 cup	0.7
Apple juice	¾ cup	0.2
Tea with	1 cup	0
sugar	1 tsp	0
Total		10.4

CRITICAL THINKING QUESTIONS

- Based on the diet shown here, what factors contributed to Hanna's iron deficiency?
- Suggest two changes in Hanna's vegetarian diet that would increase her iron intake.
- Suggest two changes in Hanna's diet that would help to increase the absorption of the iron she consumes.
- Suggest substitutions that would increase her intake of calcium.
- Are there other nutrient deficiencies for which she may be at risk?

iProfile Use iProfile to compare the amount of iron in the dark meat and white meat of poultry.

increase the risk of diabetes is poorly understood, but a relationship between higher serum iron levels and lower levels of proteins that increased insulin release and tissue sensitivity to insulin have been identified, supporting a link between iron metabolism and the risk of type 2 diabetes.[14] The increase in free radical formation that occurs when iron levels are high has been hypothesized to increase cancer risk. Although a review of epidemiological evidence did not find an association between high iron stores and increased cancer risk, high intake of heme iron was

Charles D. Winters

Nutrition Facts
Serving Size 1/4 cup (40g)

Amount Per Serving	
Calories 130	**Calories from Fat** 0
	% Daily Value*
Total Fat 0g	0%
Saturated Fat 0g	0%
Trans Fat 0g	0%
Cholesterol 0mg	0%
Sodium 10mg	0%
Total Carbohydrate 31g	10%
Dietary Fiber 2g	9%
Sugars 29g	
Protein 1g	
Vitamin A	0%
Vitamin C	0%
Calcium	2%
Iron	6%

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:

	Calories	2,000	2,500
Total Fat	Less Than	65g	80g
Sat. Fat	Less Than	20g	25g
Cholesterol	Less Than	300mg	300mg
Sodium	Less Than	2,400mg	2,400mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Calories per gram:
Fat 9 Carbohydrate 4 Protein 4

FIGURE 12.7 Iron on food labels
The foods in the photo are good sources of iron. Because iron is a nutrient at risk for deficiency in the American diet, the iron content of packaged foods must be listed on food labels. On the current food label it is given as a percentage of the Daily Value, which is 18 mg for adults. On proposed food labels the amount of iron will be given both in milligrams and as a percentage of the Daily Value.

THINK CRITICALLY

If you ate a small box of raisins, which provides 6% of the Daily Value for iron, what additional foods could you consume throughout the day to meet your iron needs?

associated with a greater risk of cancer.[15] To avoid iron overload, iron supplements are not recommended for adult men and postmenopausal women unless prescribed by a physician.[4]

How to Get Enough Iron

Both the amount and the bioavailability of iron from the diet need to be considered when planning a diet to meet iron needs (see **Critical Thinking: Increasing Iron Intake and Uptake**). The best food sources of iron are red meats and organ meats such as liver and kidney because they provide the more absorbable heme iron. Good nonheme iron sources are legumes, dried fruit, leafy greens such as spinach and kale, and fortified grain products. Nonheme iron absorption can be enhanced by including meat, fish, poultry, and foods rich in vitamin C in meals containing iron while decreasing the consumption of dairy products, which are high in calcium, at these meals.[3] Food labels can help identify good sources of iron (Figure 12.7).

Although diet is the ideal way to meet iron needs, supplements are often recommended for groups at risk for deficiency such as small children, women of childbearing age, and pregnant women. Iron is commonly available as an individual supplement or as part of multivitamin and mineral supplements. These contain nonheme iron. As with nonheme iron in the diet, to enhance the absorption of iron in a supplement, it should be consumed with foods containing vitamin C, such as orange juice; taken with a meal containing meat, fish, or poultry; and not taken with dairy products, calcium supplements, or substances that bind iron. Iron from supplements that contain the ferrous form (Fe^{2+}) of iron, such as ferrous sulfate, is more readily absorbed than iron from those with the ferric form (Fe^{3+}). Iron supplements can improve iron status, but large intakes of iron from supplements can cause toxicity symptoms and interfere with the absorption of zinc and copper. Iron-containing supplements should be taken only as suggested on the label or prescribed by a physician (Table 12.1).

TABLE 12.1 Benefits and Risks of Trace Element Supplements

Supplement	Claims	Actual benefits or risks
Iron	Increases energy.	Needed to make hemoglobin to deliver oxygen to tissues. Supplements are beneficial if iron is deficient. High doses cause constipation, liver damage, and death.
Zinc	Treats colds, prevents aging, improves immune function, enhances fertility.	Needed for enzyme function, protein synthesis, and vitamin and hormone function. Supplements do not enhance these effects. Zinc lozenges do not prevent colds but may reduce their duration. High doses cause copper deficiency, nausea, and vomiting.
Copper	Prevents heart disease and osteoporosis. Alleviates arthritis symptoms, maintains healthy skin and hair color, treats hypoglycemia.	Supplements are useful for improving bone health and improving blood lipids in those with copper deficiency, but there is no evidence that intakes above recommended levels prevent heart disease or are effective for the treatment of arthritis or skin conditions. High doses can cause vomiting.
Selenium	Protects against cancer, promotes heart health, stimulates immune function.	Antioxidant; adequate levels protect against cancer. High doses can increase the risk of cancer and cause loss of hair and nail changes.
Chromium	Controls diabetes, lowers cholesterol, reduces body fat, increases lean tissue.	Needed for insulin action. Supplements may improve blood sugar regulation but do not affect body composition.
Vanadium	Aids insulin action; allows more rapid and intense muscle pumping for body builders.	No evidence to support a benefit for body builders. Supplements can reduce insulin requirements, but the dose required exceeds the UL.

12.4 Zinc (Zn)

LEARNING OBJECTIVES

- List some dietary sources of zinc.
- Describe how zinc absorption is regulated.
- Discuss the role of zinc in gene expression.

The essentiality of zinc in the human diet was first recognized over 50 years ago, when a syndrome of growth depression and delayed sexual development, seen in Iranian and Egyptian men consuming diets based on vegetable protein, was alleviated by supplemental zinc.[16] Although their diet was not low in zinc, it was high in grains containing phytates, which interfered with zinc absorption and caused their zinc deficiency.

Zinc in the Diet

Zinc is found in foods from both plant and animal sources. Zinc from animal sources is better absorbed than that from plants because the zinc in plant foods is often bound by phytates. Zinc is abundant in red meat, liver, eggs, dairy products, vegetables, and some seafood (Figure 12.8). Whole grains are a good source, but refined grains are not because zinc is lost in milling and not added back in enrichment. Grain products leavened with yeast provide more zinc than unleavened products because the yeast leavening of breads reduces the phytate content.[8]

Zinc in the Digestive Tract

The gastrointestinal tract is the major site for regulation of zinc homeostasis. Both the amount of zinc in the mucosal cells and the amount that leaves these cells for distribution to the rest of the body are regulated.

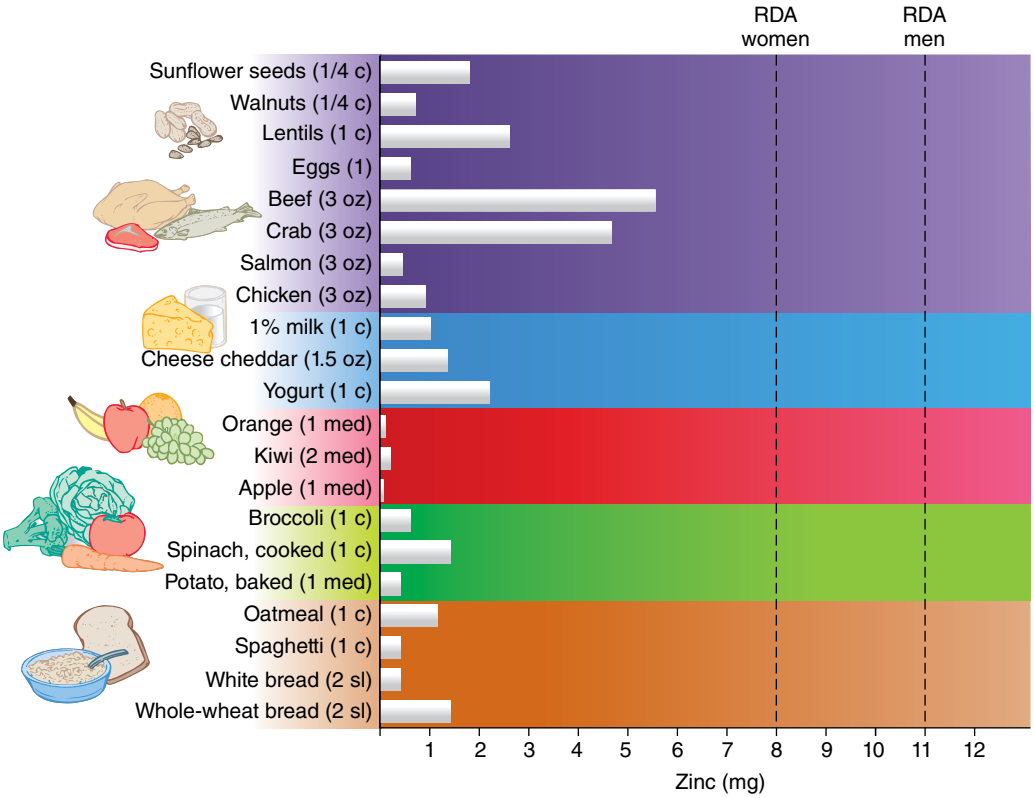


FIGURE 12.8 Zinc content of MyPlate food groups
Meat, seafood, dairy products, and whole grains are good sources of zinc; the dashed lines represent the RDAs for adult women and men.

Zinc transport proteins regulate the amount of zinc in the cytosol of the mucosal cells. Some of these proteins increase the amount of zinc absorbed into the mucosal cell by promoting the transport of zinc from the intestinal lumen into the cell. Others reduce the amount of zinc in the cytosol of the mucosal cell by transporting zinc back into the lumen or into storage vesicles in the cell (Figure 12.9).[17] The amount of zinc that is in the cytosol and is transported into the blood can be regulated by increasing or decreasing the synthesis of proteins that transport zinc into versus those that transport it back out of the mucosal cells.[18] For example, if zinc intake is high (see Figure 12.9A), expression of zinc transport proteins that move zinc from the lumen into the mucosal cells will decrease relative to the expression of proteins that export zinc out of the mucosa. Low zinc levels will have the opposite effect, decreasing zinc export to the lumen relative to transport into the cell (see Figure 12.9B).

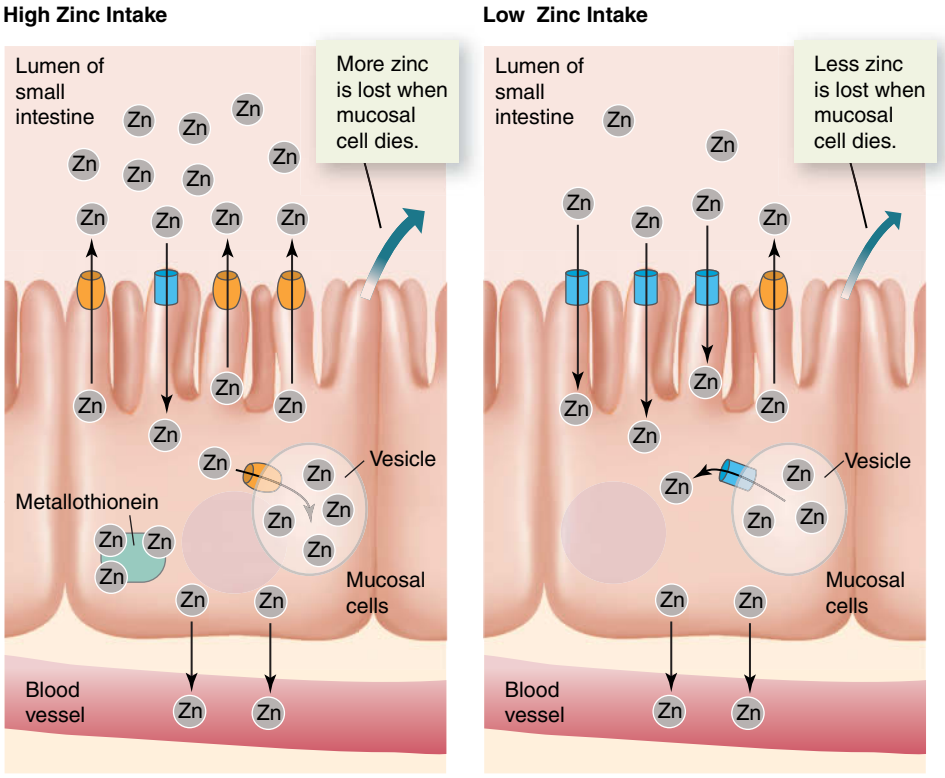
The amount of zinc that passes from the mucosal cell into the blood is also regulated by a metal-binding protein called **metallothionein**.[18] When zinc intake is high, metallothionein synthesis increases. Zinc in the mucosal cell binds to metallothionein, slowing its transfer into the blood; this provides more opportunity for zinc to be exported back into the lumen when zinc intakes are high or for it to be lost if the mucosal cell dies (see Figure 12.9A). Metallothionein also binds copper, and high levels can inhibit copper absorption.

metallothionein A group of proteins that bind metals. One such protein binds zinc and copper in intestinal cells, limiting their absorption into the blood.

How Zinc Functions in the Body

Zinc is the most abundant intracellular trace element. It is found in the cytosol, in cellular organelles, and in the nucleus. Once zinc has been absorbed, homeostasis can be maintained to some extent by regulating excretion. Zinc is secreted in pancreatic and intestinal juices, which enter the lumen of the intestine. When zinc levels in the body are low, the zinc that enters the gastrointestinal tract can be reabsorbed and recycled. When levels in the body are high, less is reabsorbed and more is therefore eliminated in the feces.

FIGURE 12.9 Regulation of zinc absorption



A. When zinc intake is high, fewer of the zinc transport proteins (shown in blue) are available to move zinc from the lumen into the cells and more zinc transporters (shown in orange) move zinc out of the mucosal cells into the lumen and from the cytosol into storage vesicles. The synthesis of metallothionein, which binds zinc and limits its uptake into the blood, increases. This allows the body to lose zinc when the cells die.

B. When zinc intake is low, more zinc transport proteins (shown in blue) are available to move zinc from the lumen of the intestine into the mucosal cells and from storage vesicles into the cytosol. Little metallothionein is synthesized, so zinc is not retained in the mucosal cells and thus is not lost when the cells die.

Zinc Is Needed for Many Cellular Activities Zinc is involved in the functioning of over 300 different enzymes, including a form of **superoxide dismutase (SOD)**, which is vital for protecting cells from free radical damage. Zinc is needed to maintain adequate levels of metallothionein proteins, which also scavenge free radicals. Zinc is essential for the activity of enzymes that function in the synthesis of proteins, DNA, and RNA; in carbohydrate metabolism; in acid–base balance; and in a reaction that is necessary for the absorption of folate from food. Zinc plays a role in the storage and release of insulin, the mobilization of vitamin A from the liver, and the stabilization of cell membranes. It influences hormonal regulation of cell division and is therefore needed for the growth and repair of tissues, the activity of the immune system, and the development of sex organs and bone.

superoxide dismutase (SOD) An enzyme that protects the cell by neutralizing damaging superoxide free radicals. One form of the enzyme requires zinc and copper for activity, and another form requires manganese.

Zinc Regulates Gene Expression Some of the functions of zinc can be traced to its role in gene expression. For example, zinc stimulates the production of metallothionein by binding to a regulatory factor and activating the transcription of the gene for this protein. Zinc also plays a structural role in proteins essential for gene expression. Proteins containing zinc fold around the zinc atom to form a loop or "finger." These zinc fingers allow nuclear receptor proteins to bind to regulatory regions on DNA, stimulating the transcription of specific genes and therefore the synthesis of the proteins for which they code. For example, the retinoic acid-receptor protein contains zinc fingers. When it binds to vitamin A (retinoic acid), the zinc fingers bind to DNA, allowing gene transcription to be stimulated (Figure 12.10). Without zinc, vitamin A, as well as vitamin D and certain hormones, including the thyroid hormones, estrogen, and testosterone, cannot interact with DNA to increase or decrease gene expression and, hence, the synthesis of certain proteins.

Zinc Deficiency

Zinc deficiency has been seen in individuals with a genetic defect in zinc absorption and metabolism called *acrodermatitis enteropathica*, in those fed total parenteral nutrition (TPN) solutions lacking zinc, and in those consuming diets low in protein and high in phytates. It may also occur in individuals with kidney disease, sickle cell disease, alcoholism, cancer, or AIDS.

The symptoms of zinc deficiency include poor growth and development, skin rashes, hair loss, diarrhea, neurological changes, impaired reproduction, and reduced immune function.[19] Many of these symptoms reflect zinc's importance in protein synthesis and gene expression. Because it is needed for the proper functioning of vitamins A and D and the activity of numerous enzymes, some of the zinc deficiency symptoms resemble deficiencies of other essential nutrients. Decreased immune function is one of the main concerns with even moderate zinc deficiency.[19] The impact of zinc deficiency on immune function is rapid and extensive, causing a decrease in the number and function of immune cells in the blood, which can lead to an increased incidence of infections.

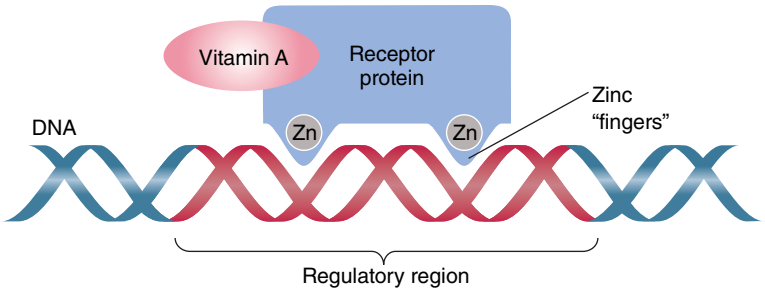


FIGURE 12.10 Zinc fingers and gene expression
Zinc fingers allow nuclear receptor proteins that bind to vitamin A (as well as vitamin D and certain hormones) to interact with the regulatory region of a gene and thus affect gene expression.

THINK CRITICALLY

How could a zinc deficiency lead to a secondary vitamin A deficiency?

Symptomatic zinc deficiency is relatively uncommon in North America. Only about 8% of the U.S. population consumes less than the EAR for zinc, but this percentage would be much higher without the zinc provided by fortified foods and supplements.[20] The risk of zinc deficiency is greater in areas of the world where the diet is low in zinc and high in phytates, as it is in many developing countries. It is estimated that over 17% of the world's population is at risk of inadequate zinc intake, with the highest prevalence in Sub-Saharan Africa and South Asia.[21] In the developing world, zinc deficiency decreases linear growth and increases the risk of infection and overall mortality in children.[22] In addition to children, pregnant women, the elderly, and vegans are at particular risk.

Recommended Zinc Intake

The RDA for zinc is 11 mg/day for adult men and 8 mg/day for adult women. This is based on the amount of zinc needed to replace daily losses from the body. Vegetarians may need to consume as much as 50% more zinc to meet their needs, depending on the phytate content of their diet.[8]

LIFE CYCLE

During pregnancy, the recommendation for zinc intake is increased to account for the zinc that accumulates in maternal and fetal tissues. During lactation, the RDA is increased to compensate for zinc secreted in breast milk. For infants from newborn to 6 months, an AI has been established based on the zinc intake of breast-fed infants. RDAs have been established for older infants, children, and adolescents based on the amount of zinc lost from the body, the amount needed for growth, and the absorption of zinc from the diet.

Zinc Toxicity

Zinc can be toxic when consumed in excess of recommendations. A single dose of 1 to 2 g can cause gastrointestinal irritation, vomiting, loss of appetite, diarrhea, abdominal cramps, and headaches. This has occurred with consumption of foods and beverages contaminated with zinc that has leached from galvanized containers. Intakes in the range of 50 to 300 mg/day have been shown to decrease rather than enhance immune function and to reduce HDL cholesterol, the type of cholesterol that has a protective effect against heart disease.[8] Supplements providing 50 mg/day of zinc have been shown to interfere with the absorption of copper. When high zinc intake inhibits copper absorption, a copper deficiency can result. A UL has been set at 40 mg/day from all sources based on the adverse effect of excess zinc on copper absorption and metabolism.

Zinc Supplements

Zinc is often marketed as a supplement to improve immune function and enhance fertility and sexual performance. For individuals consuming adequate zinc, there is no evidence that extra is beneficial. In individuals with a mild zinc deficiency, supplementation may result in improved

THINK CRITICALLY

Why might the zinc in a lozenge have a greater effect on cold duration than the zinc in a multivitamin/mineral supplement?

Andy Washnik

FIGURE 12.11 Zinc lozenges
Zinc lozenges are marketed to reduce the prevalence and severity of the common cold. Each lozenge contains about 11 to 14 mg of elemental zinc.

wound healing, immunity, and appetite; in children, it can result in improved growth and learning. Zinc supplements in lozenge form are currently popular for preventing and treating colds (see Table 12.1). Supplemental zinc is also used therapeutically to treat genetic diseases.

Do Zinc Lozenges Relieve Cold Symptoms? American adults have an average of two to three colds a year, and children have even more; the common cold is a leading cause of missed days from school and work.[23] It has been suggested that zinc lozenges, containing either zinc gluconate or zinc acetate, reduce the duration and severity of the common cold by inhibiting the replication of the cold viruses.[24] The zinc swallowed in a mineral supplement will not have any effect because this zinc goes to your stomach and doesn't contact the mucosal surfaces in the nose and throat that are affected by cold viruses. Although clinical trials to assess the efficacy of zinc lozenges have been inconsistent, most support the value of zinc lozenges in reducing the duration of symptoms when administered within 24 hours of the onset of cold symptoms.[25] If zinc lozenges are used as a cold remedy, they should be used cautiously (Figure 12.11). Nausea, constipation, diarrhea, abdominal pain, dry mouth, and oral irritation have been reported with the use of zinc lozenges.[25] Too much zinc can also suppress the immune system, lower healthy HDL cholesterol levels, and impair copper absorption.

Supplemental Zinc to Treat Genetic Abnormalities The inherited disease *acrodermatitis enteropathica* is due to a defect in zinc absorption that results in zinc deficiency. This condition causes skin lesions, damages the eyes, and increases the risk of infection. If untreated, patients with acrodermatitis enteropathica usually die within the first few years of life. Symptoms can be reversed by providing supplemental zinc in amounts greater than 1 to 2 mg per kilogram per day for life. These large doses bypass the normal absorptive mechanisms, allowing enough zinc to get into the body. This therapy achieves a survival rate of 100%. Because treatment involves consumption of amounts well in excess of the UL, patients with this disorder must be monitored to ensure that the high zinc level does not cause copper deficiency.

Zinc supplements are also used to treat *Wilson's disease*. Wilson's disease is due to an inherited defect in the excretion of copper and causes copper to accumulate in the body, leading to toxicity. A few drugs are available to remove copper from the body, but supplemental zinc acetate, which blocks the absorption of copper, increases copper excretion in the stool, and causes no serious side effects, is considered the best treatment.[26]

12.5 Copper (Cu)

LEARNING OBJECTIVES

- Explain why copper deficiency can lead to anemia.
- Describe how high intakes of zinc affect copper absorption.

The ability of copper to treat certain types of anemia helped establish the essentiality of this mineral in human nutrition.[27] Further understanding of the impact of copper deficiency in humans came from studying individuals who were inadvertently fed intravenous (TPN) solutions deficient in copper and those with a rare genetic disease called *Menkes disease* or *kinky hair disease* in which there is a defect in intestinal copper absorption.

Copper in the Diet

The richest dietary sources of copper are organ meats and shellfish, but most of the copper we consume is from legumes, nuts and seeds, and whole-grain breads and cereals (Figure 12.12). As with many other trace minerals, soil content affects the amount of copper in plant foods.

Copper in the Digestive Tract

About 30 to 40% of the copper in a typical diet is absorbed.[8] The absorption of copper is affected by the presence of other minerals in the diet. As discussed, the zinc content of the diet can have a major impact on copper absorption. When zinc intake is high, it stimulates the synthesis of the protein metallothionein in the mucosal cells. Although metallothionein binds zinc, it binds to copper more tightly. Therefore, when metallothionein is synthesized, it binds copper, preventing it from being moved out of mucosal cells into the blood (Figure 12.13). The antagonism between copper and zinc is so great that phytates, which inhibit zinc absorption, actually increase the absorption and utilization of copper. Copper absorption is also reduced by high intakes of iron, manganese, and molybdenum. Large doses of antacids may also inhibit copper absorption and, over the long term, can cause copper deficiency.

Keith Weller/Courtesy USDA

FIGURE 12.12 Food sources of copper
Oysters, liver, Brazil nuts, blackstrap molasses, cocoa, and black pepper are excellent sources of copper. Lobster, other nuts, sunflower seeds, green olives, and wheat bran are also good sources.

How Copper Functions in the Body

Once absorbed, copper binds to albumin, a protein in the blood, and travels to the liver, where it binds to the protein **ceruloplasmin** for delivery to other tissues. Copper must be transported bound to proteins such as albumin and ceruloplasmin because free copper ions can act as pro-oxidants, triggering oxidation and leading to cellular damage. Copper can be removed from the body by secretion in the bile and subsequent elimination in the feces.

ceruloplasmin The major copper-carrying protein in the blood.

Copper functions in a number of important proteins and enzymes that are involved in iron and lipid metabolism, connective tissue synthesis, maintenance of heart muscle, and the functioning of the immune and central nervous systems.[8] The copper-containing plasma protein ceruloplasmin converts iron into a form that can bind to transferrin for transport from body cells, and an analogous copper-containing protein found in intestinal cells is essential for the transport of absorbed iron from the intestine. Copper is an essential component in a form of the antioxidant enzyme superoxide dismutase. Copper also plays a role in cholesterol and glucose metabolism; elevated blood cholesterol levels have been reported in copper deficiency. Copper is needed for the synthesis of the neurotransmitters norepinephrine and dopamine and several blood-clotting factors. It may also be involved in the synthesis of myelin, which is necessary for transmission of nerve signals.

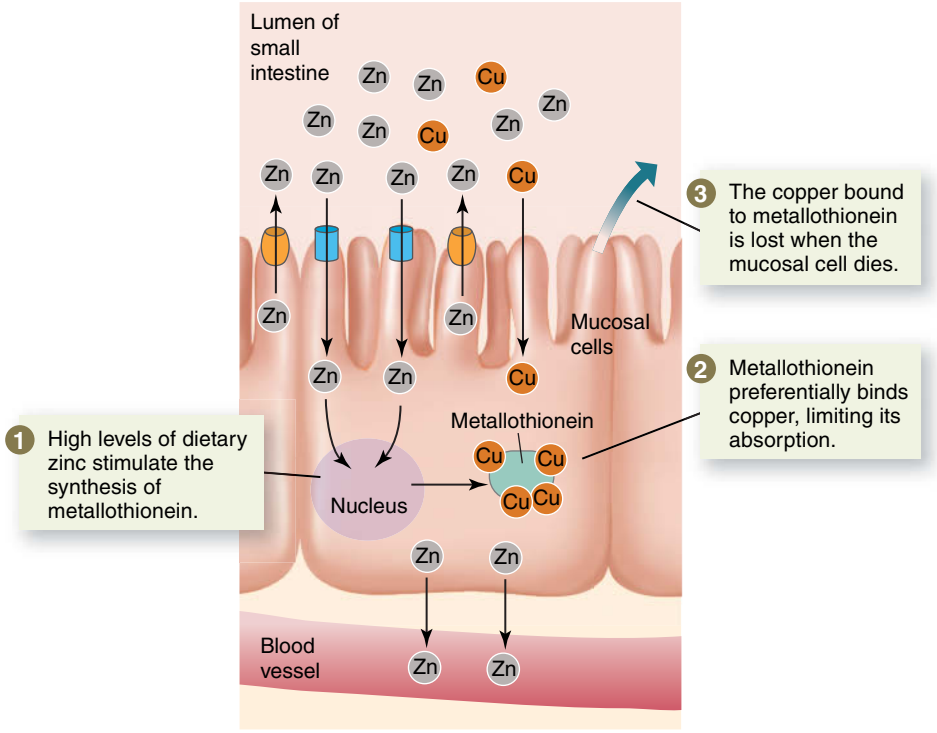


FIGURE 12.13 Inhibition of copper absorption by zinc
High levels of dietary zinc can inhibit copper absorption by stimulating the synthesis of metallothionein, which then preferentially binds copper and limits its absorption.

Copper Deficiency

Severe copper deficiency is relatively rare, occurring most often in preterm infants. Marginal copper deficiency may be more prevalent but has been difficult to diagnose. The most common manifestation of copper deficiency is anemia. This is due primarily to the importance of copper-containing proteins in iron transport. In copper deficiency, even if iron is sufficient in the diet, iron cannot be transported out of the intestinal mucosa. Copper deficiency also causes connective tissue abnormalities similar to those seen in vitamin C deficiency (scurvy). This is because the enzyme needed for the cross-linking of connective tissue proteins requires copper. Copper deficiency has also been associated with impaired growth, degeneration of the heart muscle, degeneration of the nervous system, and changes in hair color and structure.[8] Because of copper's role in the development and maintenance of the immune system, a diet low in copper decreases the immune response and increases the incidence of infection.[28]

Recommended Copper Intake

The RDA for copper for adults is 900 μg/day. This recommendation is based on the amount of copper needed to maintain normal blood levels of copper and ceruloplasmin. During pregnancy, the RDA is increased to 1000 μg/day to account for the copper that accumulates in the fetus and maternal tissues. The RDA for lactation is 1300 μg/day to account for the copper secreted in human milk. The amount of copper in the North American diet is slightly above the RDA.

Copper Toxicity

Copper toxicity from dietary sources is extremely rare but has occurred as a result of drinking from contaminated water supplies or consuming acidic foods or beverages that have been stored in copper containers. Excessive copper intake causes abdominal pain, vomiting, and diarrhea. These symptoms may occur with copper intakes of 4.8 mg/day in some individuals, but there is evidence that people can adapt to higher exposures without experiencing any adverse effects. High doses of copper have also been shown to cause liver damage. The UL has been set at 10 mg of copper per day.[8]

12.6 Manganese (Mn)

LEARNING OBJECTIVE

- Discuss the antioxidant function of manganese, copper, and zinc.

The best dietary sources of manganese are whole grains, legumes, and nuts (Figure 12.14). Fruits and vegetables are fair sources; meat, dairy products, and refined grains are poor sources.

Rita Maas/The Image Bank

FIGURE 12.14 Food sources of manganese
Legumes, nuts, and whole grains are high in manganese.

How Manganese Functions in the Body

Manganese homeostasis is maintained by regulating both absorption and excretion. Manganese absorption increases when intake is low and decreases when intake is high. Manganese is eliminated by secretion into the intestinal tract in bile.

Manganese is a constituent of some enzymes and an activator of others. Manganese-requiring enzymes are involved in amino acid, carbohydrate, and cholesterol metabolism; cartilage formation; urea synthesis; and antioxidant protection. Like copper and zinc, manganese is needed for the activity of a form of superoxide dismutase. The form of the enzyme requiring manganese is located inside the mitochondria.

Manganese Deficiency and Toxicity

Manganese deficiency in animals results in growth retardation, reproductive problems, congenital malformations in the offspring, and abnormalities in brain function, bone formation, glucose regulation, and lipid metabolism.

Although a naturally occurring manganese deficiency has never been reported in humans, a man participating in a study of vitamin K was inadvertently fed a diet

deficient in manganese for six months. He lost weight, his black hair turned a red color, and he developed dermatitis and low blood cholesterol. Manganese deficiency was further studied in young male volunteers fed a manganese-deficient diet for 39 days. These men developed dermatitis and had altered blood levels of cholesterol, calcium, and phosphorus.[29]

Toxic levels of manganese result in damage to the nervous system. In humans, toxicity has been reported in mine workers exposed to high concentrations of inhaled manganese dust. The UL is 11 mg/day from all sources.[8]

Recommended Manganese Intake

There is not sufficient evidence to set an RDA for manganese; the AI is 2.3 mg/day for men and 1.8 mg/day for women. Recommended intakes are higher during pregnancy and lactation.[8]

12.7 Selenium (Se)

LEARNING OBJECTIVES

- Compare the antioxidant functions of selenium and vitamin E.
- Explain why the amount of selenium in the soil may impact the selenium status of certain populations.
- Discuss the relationship between selenium and cancer.

Although selenium was discovered about 180 years ago, its essential role in human nutrition was not recognized until the 1970s, when it was found to prevent a heart disorder in children living in regions of China with low soil selenium levels. Today, selenium is known to be an important part of the body's antioxidant defenses.

Selenium in the Diet

Seafood, kidney, liver, and eggs are excellent sources of selenium (Figure 12.15). Grains, seeds, and dairy products are good sources and fruits, vegetables, and drinking water are generally

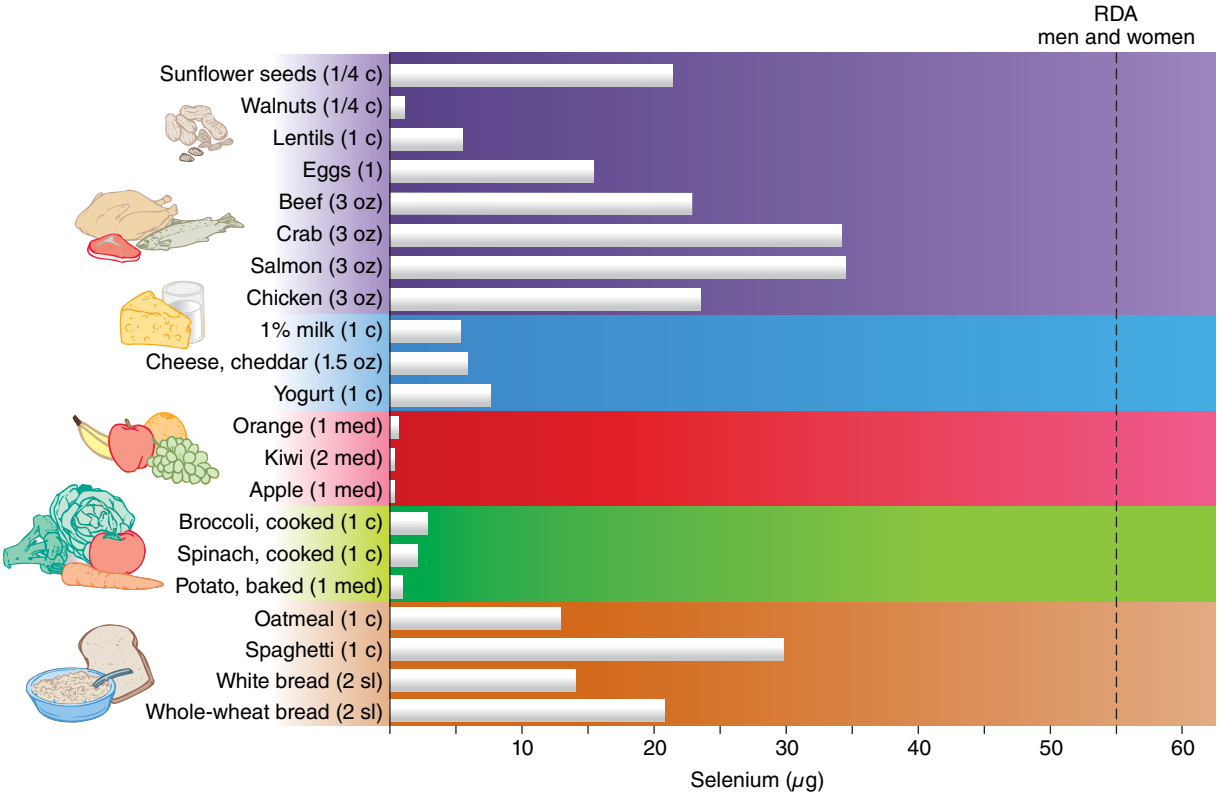


FIGURE 12.15 Selenium content of MyPlate food groups
Both plant and animal foods are good sources of selenium. The dashed line represents the RDA for adults.

selenoproteins Proteins that contain selenium as a structural component of their amino acids. Selenium is most often found as selenocysteine, which contains an atom of selenium in place of the sulfur atom.

poor sources. The selenium content of plant foods depends on the selenium content of the soil where they were grown and the content of animal products is affected by the amount of selenium in their feed.[30] For example, wheat grown in the Midwest may have a different selenium content from wheat grown in New England. Soil selenium can have a significant impact on the selenium intake of populations consuming primarily locally grown food. Selenium deficiency is not likely to be a problem when the diet includes foods produced in many different locations.

How Selenium Functions in the Body

glutathione peroxidase A selenium-containing enzyme that protects cells from oxidative damage by neutralizing peroxides.

Selenium absorption is efficient and does not appear to be regulated. Once absorbed, selenium homeostasis is maintained by regulating its excretion in the urine.

Selenium is a mineral that functions mostly through association with proteins called **selenoproteins**. Several of these, including **glutathione peroxidase**, are enzymes that help protect cells from oxidative damage. Glutathione peroxidase neutralizes peroxides so they no longer form free radicals, which cause oxidative damage. By reducing free radical formation, selenium can reduce the need for vitamin E because this vitamin stops the action of free radicals once they are produced (Figure 12.16). In addition to its role in glutathione peroxidase, selenium is important for the function of the thyroid gland.[30] Selenoproteins help protect the thyroid gland from reactive oxygen species, and selenium-containing enzymes are needed for the synthesis of the thyroid hormones, which regulate basal metabolic rate.

Selenium Deficiency

Symptoms of selenium deficiency include muscular discomfort, weakness, poor immune function, and cognitive decline. Deficiency was not identified in humans until the late 1970s, when it was observed in patients fed TPN solutions inadvertently deficient in selenium. At the same time scientists in China described a disease of the heart muscle called **Keshan disease**, which was linked to selenium deficiency.[31]

Keshan disease A type of heart disease that occurs in areas of China where the soil is very low in selenium. It is believed to be caused by a combination of viral infection and selenium deficiency.

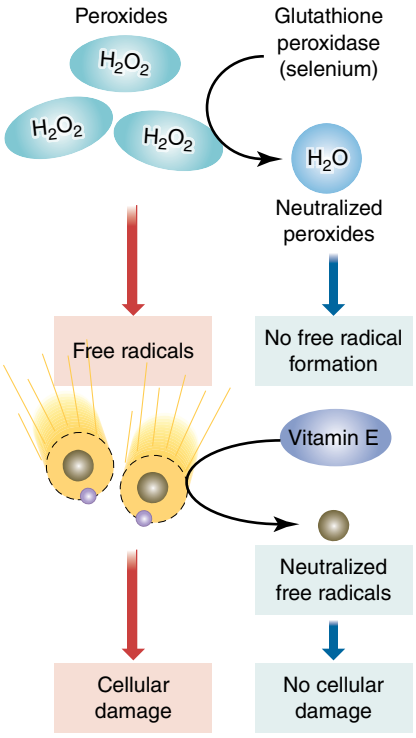


FIGURE 12.16 Glutathione peroxidase
Selenium is a part of the enzyme glutathione peroxidase, which neutralizes peroxides before they form free radicals. Fewer free radicals means less vitamin E is needed to eliminate them.

Selenium Deficiency and Keshan Disease

Keshan disease causes an enlarged heart and poor heart function. It used to be endemic in regions of China where the diet was restricted to locally grown food and the soil was deficient in selenium (Figure 12.17). It affected primarily children and women of childbearing age. Selenium supplementation was found to dramatically reduce the incidence of Keshan disease, but it could not reverse heart damage once it had occurred. Although Keshan disease is now virtually eliminated by selenium supplementation, the disease itself is believed to be due to a combination of selenium deficiency and infection with a virus. When selenium is deficient, the virus becomes more virulent, causing the symptoms of Keshan disease.[31]

How Selenium Status Is Related to Cancer

The role of selenium in cancer has been under investigation for three decades. An increased incidence of cancer has been observed in regions where selenium intake is low. In 1996 a study investigating the effect of selenium supplements on people with a history of skin cancer found that the supplements had no effect on the recurrence of skin cancer, but that the incidence of lung, prostate, and colon cancer all decreased in the selenium-supplemented group.[32] There was a great deal of excitement about this result, and many believed selenium supplements could reduce cancer risk. Subsequent research, however, has not supported this result. Evidence now suggests that selenium supplements actually increase the incidence of certain types of cancer.[33] The reduction in the incidence of lung and prostate cancer seen in the 1996 study is now believed to have occurred primarily in people who began the study with low levels of selenium. Selenium deficiency can increase the risk of cancer, so selenium supplements would

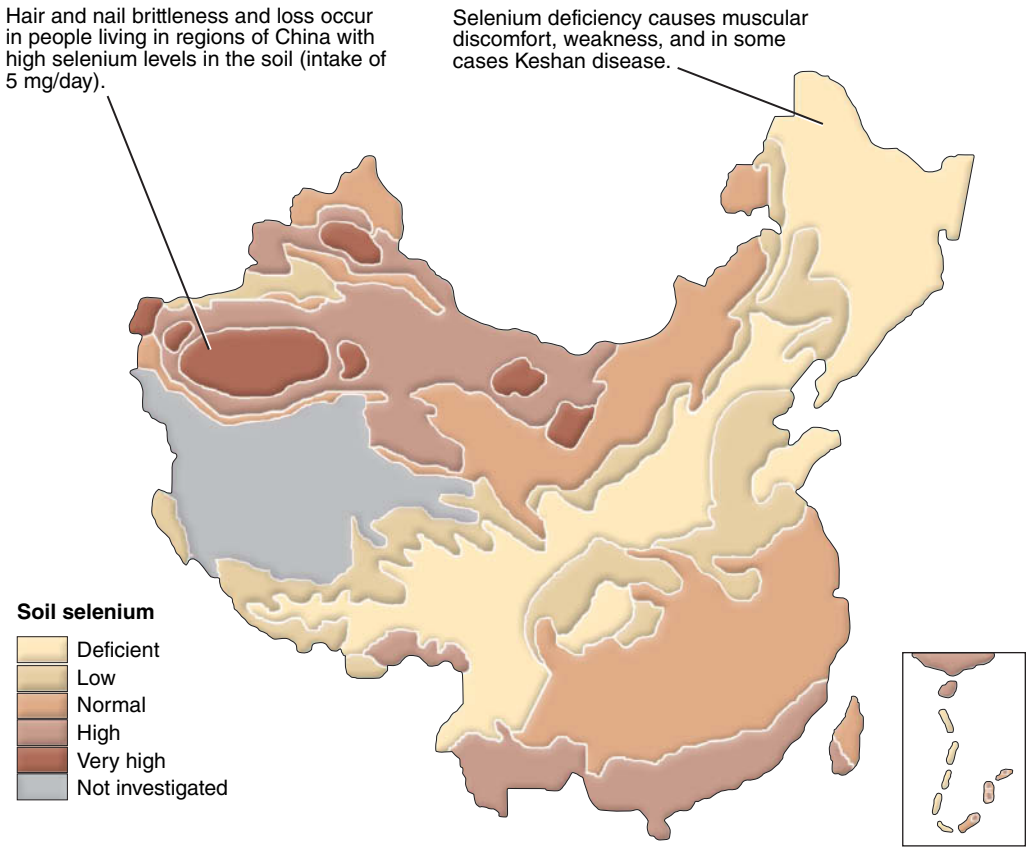


FIGURE 12.17 Soil selenium and selenium status in China
The amount of selenium in the soil affects the selenium content of crops grown in the soil. Keshan disease is most prevalent in the selenium-deficient soil zone that crosses China from the northeast to the southwest. Selenium toxicity symptoms occur in areas of China that have high soil selenium.

benefit people with low selenium status, but in those with adequate selenium status supplementation may actually increase the risk of cancer [33] (see **Debate: Antioxidant Supplements: Helpful or Harmful?**).

Recommended Selenium Intake

The RDA for selenium for adults is 55 μg/day.[34] This is based on the amount needed to maximize the activity of the enzyme glutathione peroxidase in the blood. The estimated average intake of selenium in the United States meets or nearly meets this recommendation for all age groups.

LIFE CYCLE

An increase in selenium intake is recommended during pregnancy based on the amount transferred to the fetus and during lactation to account for the amount of selenium secreted in milk. The AI for infants is based on the amount contained in breast milk.

Selenium Toxicity and Supplements

Selenium toxicity can result from oversupplementation or high levels in the food supply. Symptoms include brittle hair; brittle, thickened fingernails and toenails, leading to nail loss in some cases; and a garlic odor on the breath and skin. Hair and fingernail losses from selenium toxicity have been reported in a high-selenium region of China where selenium intake was estimated to be almost 5000 μg/day (see Figure 12.17).[35] Selenium toxicity has also been reported in the United States because of a manufacturing error that created mineral supplements containing a dose of 27 mg of selenium per day. The individuals who used these supplements had symptoms that included nausea, diarrhea, and abdominal pain as well as fingernail and hair changes.[29] The UL for adults is 400 μg/day from diet and supplements combined.[34]

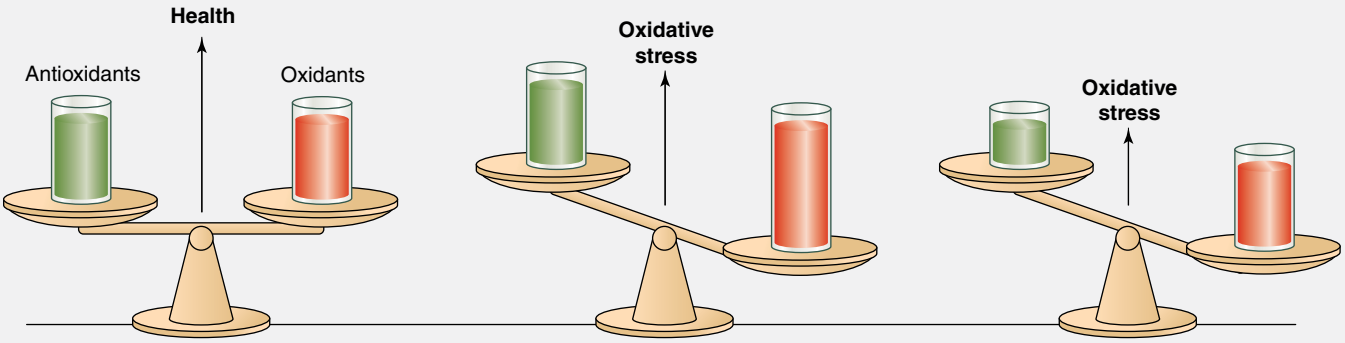
DEBATE

Antioxidant Supplements: Helpful or Harmful?

Diets rich in antioxidants from fruits, vegetables, and whole grains are associated with a reduced incidence of chronic diseases. Many of the antioxidants present in these foods are marketed as supplements to fight cancer, protect us from heart disease, and defend against age-related cell damage. Should we be taking these antioxidant supplements to help us stay young and healthy or are they dangerous?

The rationale for promoting extra antioxidants is that we need them to protect us from oxidative damage. Oxidative damage is caused by exposure to oxygen and other reactive oxygen species, referred to as *oxidants*. It alters the structure of DNA, protein, and lipid molecules and is believed to play a role in aging as well as cancer, cardiovascular disease, and diabetes. Antioxidants protect against damage from free radicals and other oxidants, and are therefore vital to our survival. However, overexposure to antioxidants can also be dangerous to our health. Not all free radicals are harmful. Some are helpful. For example, the immune system produces free radicals that help destroy foreign invaders. There must be a balance that allows free radicals generated by the immune system to work while preventing unwanted free radicals from causing damage.

If too many oxidants are generated, the body's antioxidant defenses are overwhelmed, a condition referred to as *oxidative stress*, and cell damage and death can result (see figure). Those who support the use of antioxidant supplements believe that extra antioxidants can prevent oxidative stress and help us live



Our health depends on maintaining a balance between the production of oxidants (shown in orange) and the availability and effectiveness of antioxidant defenses (shown in green) to neutralize these. When an imbalance occurs, either because the production of oxidants is too high (middle) or the availability of antioxidants too low (right), oxidative stress results.

Selenium supplements are marketed with claims that they will protect against environmental pollutants, prevent cancer and heart disease, slow the aging process, and improve immune function. Although selenium does play a role in these processes, supplements that increase intake above the RDA will not provide additional benefits and can increase the risk of toxicity.[38]

12.8 Iodine (I)

LEARNING OBJECTIVES

- Describe the function of iodine.
- Explain why iodine deficiency causes the thyroid gland to enlarge.
- Discuss factors that impact the iodine status of a population.

Iodine is needed for the synthesis of thyroid hormones. In the early 1900s, iodine deficiency was common in the central United States and Canada, but it has virtually disappeared due to the addition of iodine to table salt. Iodine deficiency, however, remains a world health problem.

longer, healthier lives. If your diet is deficient in these nutrients, increasing your intake with a supplement will enhance antioxidant defenses. But supplementing these nutrients to levels above the recommended intake may not be beneficial. A meta-analysis, which is an analysis that combines the results of many studies, has concluded that antioxidant supplementation does not prevent cancer, cardiovascular diseases, or death and that supplements of β-carotene, vitamin E, and vitamin A may increase mortality.[36]

Not everyone is convinced by these findings. There is good evidence that individuals with low levels of antioxidants such as β-carotene, selenium, and vitamin E are at increased risk of cardiovascular disease, cancer, and overall mortality, so restoring levels with supplements would be beneficial in these situations.[37,38] Skeptics also point out the benefits of some individual antioxidant supplements on specific conditions in certain individuals. For example, a combination of dietary antioxidant supplements has been shown to slow the progression of age-related macular degeneration.[39] Despite this evidence of benefits, there is also evidence of risks. For example, β-carotene supplements increase the risk of lung cancer in smokers, and one analysis found supplemental vitamin E to increase prostate cancer.[40,41] In those with adequate to high selenium status, supplements of selenium have been associated with an increased risk of cancer and type 2 diabetes.[38]

Most agree that we need more information about optimum antioxidant doses and the risk of imbalances before recommendations can be made about whether to take antioxidant supplements and, if so, how much. Just because high intakes of antioxidants from fruits and vegetables reduce the risk of heart disease does not mean the amounts and combinations in supplements will have the same effect.[42] A deficiency of one antioxidant could increase the need for another, and an excess of one may create a deficiency of another. For instance, vitamin C is necessary to regenerate the active form of vitamin E, selenium reduces some of the need for vitamin E, and excesses of zinc can cause copper deficiency. Antioxidants also have biological effects independent of their antioxidant actions; these effects may adversely affect health when intake is high.

Everyone agrees that antioxidant nutrients are important for good health. Eating more fruits, vegetables, and whole grains will boost the intake of antioxidant nutrients and benefit health, but supplements of these antioxidant nutrients may not be beneficial, particularly in well-nourished populations.[36] Foods provide fiber and phytochemicals that don't come in a supplement, and the antioxidants in food are present in ratios and with other dietary components known to promote rather than harm health. Five centuries ago, Paracelsus understood that any compound is toxic if the dose is too high, and this is likely as true for antioxidants as for supplements of any other nutrients.

THINK CRITICALLY: How could a substance that decreases free radical formation be harmful?

Iodine in the Diet

The iodine content of foods varies depending on the soil where plants are grown or where animals graze. Iodine is found in seawater, so seafood and plants grown in or near the sea are high in iodine. The soil in inland areas is generally low in iodine, so plants grown inland have lesser amounts.

Most of the iodine in the North American diet comes from salt fortified with iodine, referred to as *iodized salt*. Iodized salt contains about 100 μg of iodine per gram. It is commonplace in the United States and only iodized salt is sold in Canada. Iodized salt should not be confused with sea salt, which is a poor source of iodine because the iodine is lost in the drying process.

Iodine in our diet also comes from contaminants and additives in foods. Dairy products may contain iodine because of the iodine-containing additives used in cattle feed and the use of iodine-containing disinfectants on cows, milking machines, and storage tanks. Iodine-containing sterilizing agents are also used in food-service establishments, and iodine is used in dough conditioners and some food colorings.

How Iodine Functions in the Body

Iodine is absorbed completely and rapidly from the gastrointestinal tract in the form of iodide ions. Iodine can be eliminated from the body by excretion in the urine. More than half of the iodine

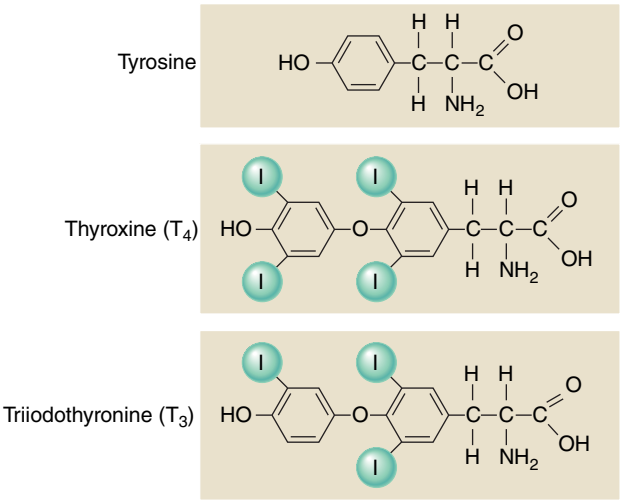


FIGURE 12.18 Structure of the thyroid hormones
The thyroid hormones thyroxine (T_4) and triiodothyronine (T_3) are made by attaching iodine to the amino acid tyrosine.

in the body is located in the thyroid gland in the front of the neck. It is concentrated here because it is an essential component of the thyroid hormones, thyroxine (T_4) and triiodothyronine (T_3), which are made from the amino acid tyrosine (Figure 12.18). T_4 is the predominant thyroid hormone in the blood and is converted into the active T_3 form by a selenium-containing enzyme. The thyroid hormones act by affecting gene expression in target cells in a manner similar to vitamins A and D (Figure 12.19). Through gene expression, thyroid hormones promote protein synthesis and regulate basal metabolic rate, growth, and development.

Levels of the thyroid hormones are carefully controlled. If blood levels drop, **thyroid-stimulating hormone (TSH)** is released from the anterior pituitary. This hormone signals the thyroid gland to take up iodine and synthesize thyroid hormones. When the supply of iodine is adequate, thyroid hormones can be made and their presence turns off the synthesis of thyroid-stimulating hormone (Figure 12.20).

thyroid-stimulating hormone (TSH) A hormone that stimulates the synthesis and secretion of thyroid hormones from the thyroid gland.

Iodine Deficiency

Iodine deficiency reduces the production of thyroid hormones. Metabolic rate slows with insufficient thyroid hormones, causing fatigue and weight gain. The most obvious outward sign of deficiency is an enlarged thyroid gland called a **goiter**. A goiter forms when reduced thyroid hormone levels cause TSH to be released, stimulating the thyroid gland to make more thyroid hormones.

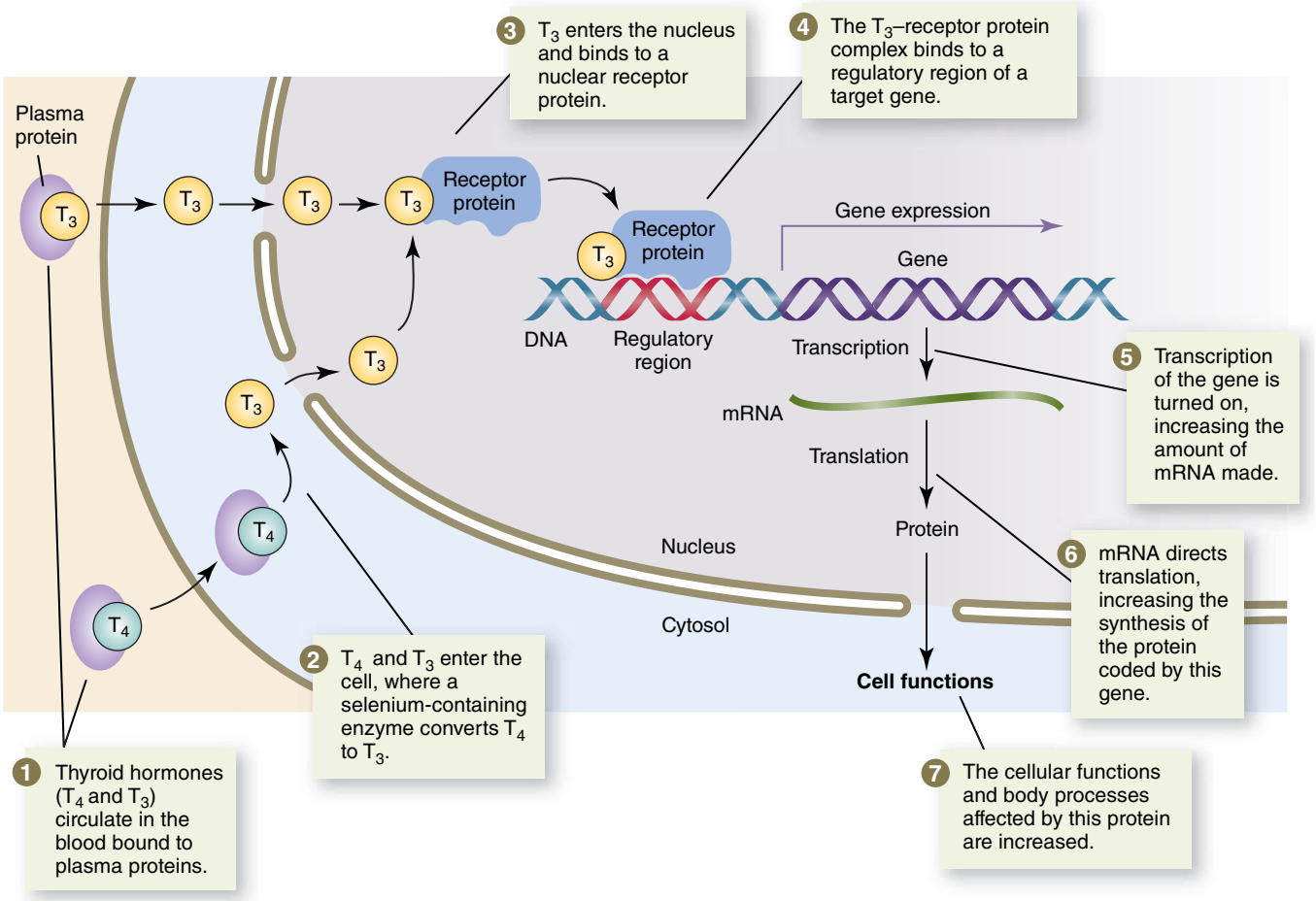
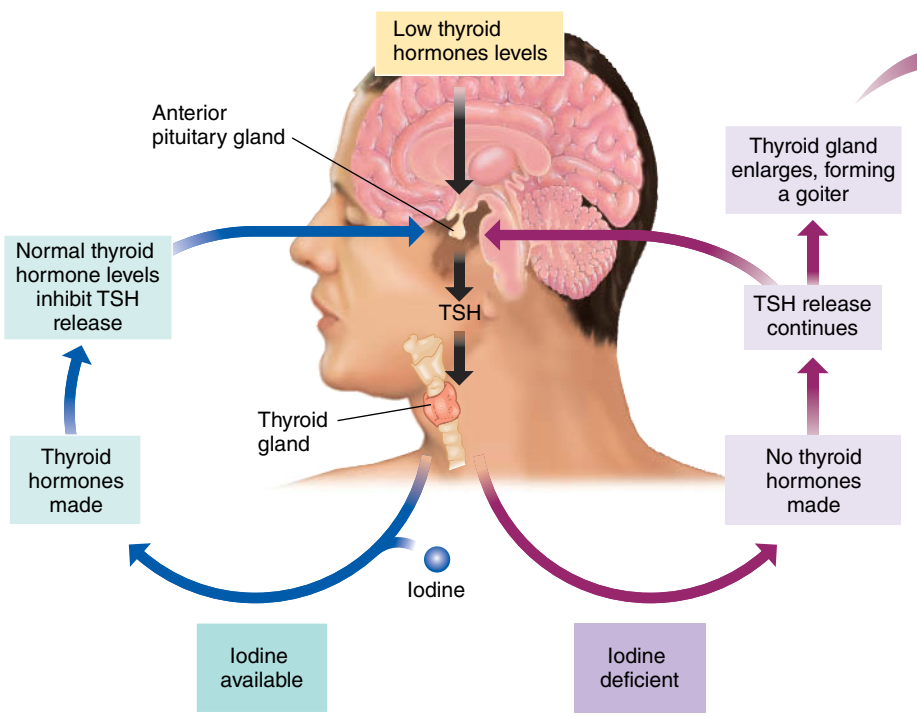


FIGURE 12.19 Role of thyroid hormones in gene expression



© Mike Goldwater/Alamy Limited

FIGURE 12.20 Thyroid hormone regulation and goiter
When thyroid hormone levels drop too low, TSH is released and stimulates the thyroid gland to take up iodine and synthesize more hormones (blue arrows). If iodine is not available (purple arrows), thyroid hormones cannot be made and the stimulation continues. This causes the thyroid gland to enlarge, forming a goiter.

THINK CRITICALLY

Why does the thyroid gland enlarge when iodine is deficient?

Because iodine is unavailable, thyroid hormones cannot be made and the stimulation continues, causing the thyroid gland to enlarge (see Figure 12.20). In milder cases of goiter, treatment with iodine causes the thyroid gland to return to normal size, but in severe cases it may remain enlarged.

goiter An enlargement of the thyroid gland caused by a deficiency of iodine.

Because of the importance of the thyroid hormones for growth and development, iodine deficiency disorders occur at all stages of life. If iodine is deficient during pregnancy, it increases the risk of stillbirth and spontaneous abortion. Deficiency also can cause a condition called **cretinism** in offspring. Cretinism is characterized by symptoms such as developmental disability, deaf mutism, and growth failure. Iodine deficiency during childhood and adolescence can also result in goiter and impaired cognitive and motor development; it has been shown that iodine-deficient individuals may forfeit 15 IQ points.[43] Iodine deficiency is the world's most prevalent, yet easily preventable, cause of brain damage.[44]

LIFE CYCLE

cretinism A condition resulting from poor maternal iodine intake during pregnancy that causes stunted growth and impaired cognitive development in offspring.

Dietary Factors That Increase Iodine Deficiency Iodine deficiency is most common in regions where the soil is low in iodine and there is little access to fish and seafood, which are good sources of this mineral. The risk of iodine deficiency is also increased by consuming **goitrogens**, substances in food that interfere with the utilization of iodine or with thyroid function. Goitrogens are found in turnips, rutabaga, cabbage, cassava, and millet. When these foods are boiled, the goitrogen content is reduced because some of these compounds leach into the cooking water. Goitrogens contribute to iodine deficiency in African countries where cassava is a dietary staple. In the United States, goitrogens are not a problem because they are present in foods that are typically not consumed in significant quantities.

goitrogens Substances that interfere with the utilization of iodine or the function of the thyroid gland.

Combating Iodine Deficiency Since it was first used in Switzerland in the 1920s, iodized salt has been the major means of combating iodine deficiency. Although iodine deficiency remains a global health issue, its incidence has declined dramatically since universal salt iodization was adopted in 1993. Currently, an estimated 70% of households worldwide have access to iodized salt.[44] Because of the fortification of table salt with iodine, cretinism and goiter are now rare in North America, but iodine status, as measured by urinary iodine concentration, has been declining in the U.S. population (see **Off the Label: Should You Choose Salt Labeled "Iodized"?**).[45] Poor regulation of iodine fortification has led to excessive iodine intakes in some countries.[44]

OFF THE LABEL

Should You Choose Salt Labeled "Iodized"?

© iStockphoto

When selecting a box of salt for the kitchen cupboard, you can choose one that just says "salt" or one that is labeled "iodized salt" (see photo). Iodized salt is salt to which the trace mineral iodine has been added. Which should you choose?

The amount of iodine you consume in your diet depends as much on where the foods are grown as on which foods you choose. Foods from the ocean or produced near it, where the soil is rich in iodine, are better sources of iodine than foods produced inland. This is because the iodine in inland areas has been washed into the oceans by glaciers, snow, rain, and floodwaters. The iodine content of plants grown in iodine-deficient soil may be 100 times less than that of plants grown in iodine-rich soil.[46]

Iodine deficiency has been known for centuries in areas where the soil is depleted. In Europe the presence of iodine deficiency was recorded in classical art, which portrayed even the wealthy with goiter and cretinism. Leonardo da Vinci is said to have been more knowledgeable about goiter than medical professors of his time. A century ago, goiter was endemic in the central regions of North America. However, the iodization of salt, which began in the early 20th century, has virtually eliminated iodine deficiency in North America, Switzerland, and other European countries.

Why fortify salt? Salt was selected as the vehicle for added iodine because it is a food item consistently consumed by the majority of the population at risk. Also, iodine can be added to salt uniformly, inexpensively, and in a form that is well utilized by the body. It can be added in amounts that eliminate deficiency with typical consumption but do not cause toxicity in people consuming larger amounts of iodized salt or individuals meeting iodine needs from other sources.

George Semple

Since the introduction of iodized salt, iodine intake in the United States has been adequate, but this may be changing. This may be due to recommendations to reduce salt intake to control blood pressure and to our reliance on processed foods, which typically contain noniodized salt.[45] Also, the iodine content of milk has decreased due to a reduction in the amount of iodine added to cattle feed, and the baking industry has eliminated some of the iodine-containing dough conditioners, thus reducing the iodine content of commercially manufactured breads. If you eat little seafood, choose salt labeled "iodized" to ensure that your iodine needs are met. Even if you get enough iodine in your diet, there is little risk involved with using iodized salt when preparing food at home.

Recommended Iodine Intake

The RDA for iodine in adult men and women is 150 μg/day. This is based on the amount needed to maintain normal iodine levels in the thyroid gland. The RDA is higher during pregnancy to account for the iodine that is taken up by the fetus and during lactation to account for the iodine secreted in milk. The recommended intake for infants is based on the amount obtained from breast milk.

Iodine Toxicity

Acute toxicity can occur with very large doses of iodine. Intakes between 200 and 500 μg per kilogram of body weight have caused death in laboratory animals.[29] Chronically high intakes of iodine can cause an enlargement of the thyroid gland that resembles goiter. The UL for adults is 1100 μg of iodine per day from all sources.[8] An enlarged thyroid from excessive iodine can also occur if iodine intake changes drastically. For example, in a population with a marginal intake, a large increase in intake due to supplementation can cause thyroid enlargement even at levels that would not be toxic in a healthy population.

12.9 Chromium (Cr)

LEARNING OBJECTIVES

- Describe the relationship between blood glucose levels and chromium.
- Explain why chromium supplements are promoted to increase lean body mass.

Scientists have known since the 1950s that chromium is needed for normal glucose utilization, but only recently have they begun to understand the role of chromium in insulin function. The popular supplement chromium picolinate is promoted to increase lean body mass.

Chromium in the Diet

Dietary sources of chromium include liver, brewer's yeast, nuts, and whole grains. Milk, vegetables, and fruit are poor sources. Refined carbohydrates such as white breads, pasta, and white rice are also poor sources because chromium is lost in milling and not added back in the enrichment process. Cooking in stainless steel cookware can increase chromium intake because chromium leaches from the steel into the food.

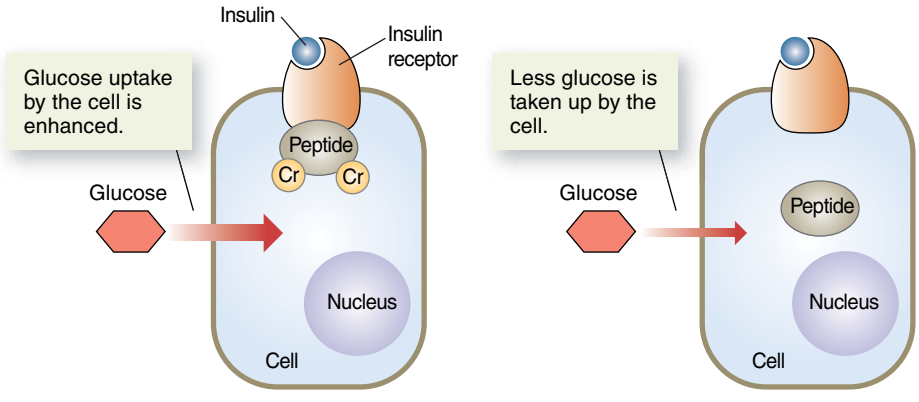
How Chromium Functions in the Body

After absorption, chromium is bound to the iron transport protein transferrin for transport in the blood. Chromium is involved in carbohydrate and lipid metabolism. When carbohydrate is consumed, insulin is released and binds to insulin receptors in cell membranes. This binding triggers the uptake of glucose by cells, an increase in protein and lipid synthesis, and other effects. Chromium is believed to act as part of a small peptide that binds to the insulin receptor after insulin is bound, enhancing its effect (Figure 12.21).[47] When chromium is deficient, it takes more insulin to produce the same effect.

Chromium Deficiency

Overt chromium deficiency is not a problem in the U.S. population. Deficiencies have been reported in patients receiving long-term TPN not containing chromium and in malnourished children. Deficiency symptoms include impaired glucose tolerance with diabetes-like symptoms, such as elevated blood glucose levels and increased insulin levels.[48] Chromium deficiency may

FIGURE 12.21 Chromium and insulin function



A. When chromium is present, a small peptide inside cells becomes active and enhances the action of insulin by binding to the insulin receptor, which increases glucose uptake.

B. When chromium is deficient, the active peptide is not formed and thus cannot bind the insulin receptor. The result is that insulin is less effective and less glucose can enter the cell.

George Semple

FIGURE 12.22 Chromium supplements
Supplements containing chromium picolinate claim to help increase lean body mass and decrease body fat.

also cause elevated blood cholesterol and triglyceride levels, but the role of chromium in lipid metabolism is not fully understood.

Recommended Chromium Intake

Based on the amount of chromium in a balanced diet, an AI has been set at 35 μg/day for men and 25 μg/day for women. The AI for women is increased during pregnancy and lactation. The AI for older adults is lower because needs decrease as energy intake decreases.

Chromium Supplements and Toxicity

Chromium supplements, particularly chromium picolinate, are marketed to reduce body fat and increase lean body mass (Figure 12.22). These claims appeal to individuals wanting to lose weight as well as to athletes trying to build muscle. Because chromium is needed for insulin action and insulin promotes protein synthesis, it is likely that adequate chromium is necessary to increase lean body mass. However, most recent studies on the effects of chromium picolinate or other chromium supplements in healthy human subjects have found no beneficial effects on muscle strength, body composition, weight loss, or other aspects of health (see Table 12.1).[49,50] Chromium supplementation has been shown to have beneficial effects on blood glucose levels in individuals with type 2 diabetes.[51]

Controlled trials have reported no dietary chromium toxicity in humans, and clinical trials with chromium picolinate have not found it to cause adverse effects.[8,51] The DRI committee concluded that there was insufficient data to establish a UL for chromium.

12.10 Fluoride (F)

LEARNING OBJECTIVES

- Identify dietary sources of fluoride.
- Discuss the role of fluoride in maintaining dental health.

The importance of fluoride for dental health has been recognized since the 1930s, when an association between the fluoride content of drinking water and the prevalence of dental caries was noted (see **Science Applied: How "Colorado Brown Stain" Led to "Look, Mom! No Cavities!"**).

Charles D. Winters

FIGURE 12.23 Dietary sources of fluoride
Most of the fluoride we consume comes from toothpaste, fluoridated water, tea, and fish eaten with bones.

Fluoride in the Diet

Fluoride is present in small amounts in almost all soil, water, plants, and animals. The richest dietary sources of fluoride are fluoridated water, tea, toothpaste, and marine fish consumed with their bones (Figure 12.23). Tea contributes significantly to total fluoride intake in countries that consume large amounts of the beverage. Brewed tea contains 1 to 6 mg of fluoride per liter, depending on the amount of dry tea used, the brewing time, and the fluoride content of the water.[52] In the United States, most of the fluoride in the diet comes from toothpaste and from fluoride added to the water supply. The U.S. Public Health Service recommends an optimal water fluoride concentration of 0.7 mg/L.[53] (Water companies often report fluoride levels in parts per million [ppm]; 1 mg/L = 1 ppm.) Because food readily absorbs the fluoride in cooking water, the fluoride content of food can be significantly increased when it is handled and prepared using fluoridated water. Cooking utensils also affect food fluoride content. Foods cooked with Teflon utensils can pick up fluoride from the Teflon, whereas aluminum cookware can decrease fluoride content. Fluoride is absorbed into the body in proportion to its content in the diet.

SCIENCE APPLIED

How "Colorado Brown Stain" Led to "Look, Mom! No Cavities!"

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

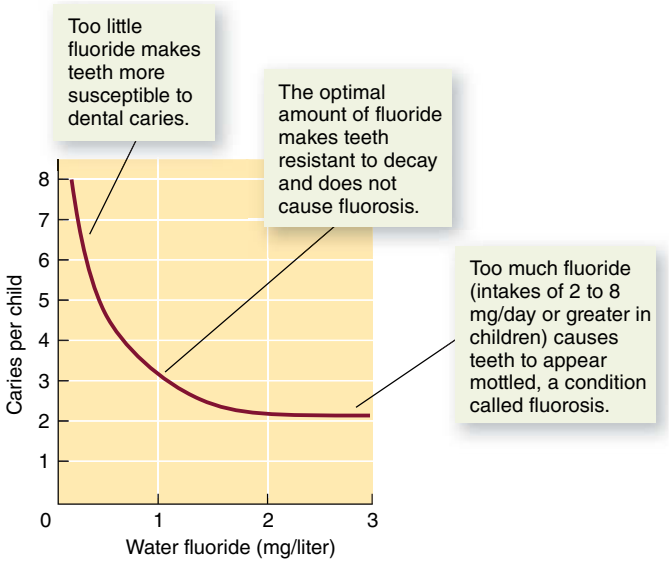
(DAJ/Getty Images, Inc.)

When Dr. Fredrick McKay set up his dental practice in Colorado Springs, Colorado, in 1901, he noticed that many of his patients had stained or mottled tooth enamel. McKay noted that those with stained teeth, a condition called "Colorado brown stain," seemed to be less susceptible to tooth decay.[54] At the time, dental caries—tooth decay—were extremely prevalent, there was no known way to prevent the disease, and the most common way to treat it was to extract the affected teeth. McKay believed that Colorado brown stain was due to something in the local water supply.

THE SCIENCE

In 1930, Dr. McKay sent water samples to a chemist for analysis. Using a new methodology called spectrographic analysis, the chemist identified high levels of fluoride, a naturally occurring element, in McKay's samples. This finding led to the establishment of the Dental Hygiene Unit at the National Institutes of Health headed by Dr. H. Trendley Dean. His task was to investigate the association between fluoride intake and mottled enamel, which he termed "fluorosis."

Dean conducted epidemiological surveys to establish the prevalence of fluorosis across the country. He noted a strong inverse relationship between the presence of fluorosis and the presence of dental caries among children.[55] In other words, children with fluorosis had fewer dental caries. Further studies revealed that the protective effect of fluoride against dental caries was seen at water fluoride levels of 1 mg/L (ppm), a level low enough to cause little fluorosis (see graph). Thus, work designed to identify the harm caused by too much fluoride had discovered the benefits of enough fluoride.



The effect of water fluoridation level on dental caries in children 12 to 14 years of age.

THE APPLICATION

Dr. Dean's research led to an intervention trial to test the effectiveness of community water fluoridation for preventing caries. The trial began in 1945 and included four pairs of cities in Michigan, New York, Illinois, and Ontario, Canada. One city of each pair received the intervention—fluoridated water—and the second city served as a control. Surveys over a 13- to 15-year period found that the incidence of caries was reduced 50 to 70% among children in the communities with the fluoridated water.[56] In 1962, epidemiological studies of water consumption patterns and caries incidence in different climates and geographic locations across the country were used to make the first recommendation for an optimal range of fluoride concentration (0.7 to 1.2 mg/L) in the water supply, with the lower range suggested for warmer climates, where more water is consumed, and the higher range for colder climates.[56] The U.S. Public Health Service recently updated this guidance on optimal fluoride concentration. It now recommends that all community water systems that currently fluoridate or will initiate fluoridation use a single concentration of 0.7 mg/L of fluoride in drinking water to maintain cavity prevention benefits and reduce the risk of dental fluorosis.[53]

Although there was some political and medical opposition to fluoridation in the early 1960s, that opposition has dwindled to a few voices that still believe that water fluoridation represents a public health hazard and increases the risk of cancer; however, these beliefs are not supported by scientific fact. Based on epidemiological data and available evidence related to the adverse effects of fluoride, the small amounts consumed in drinking water do not pose a health risk.[57]

Today, 74.6% of the U.S. population that is served by a public water system receives fluoridated water.[58] Fluoride intake has also increased due to the widespread use of fluoride toothpaste and fluoridated water in foods and beverages that are distributed in nonfluoridated areas. Although dental caries remain a public health problem, increased fluoride intake, combined with advances in dental care, have dramatically improved the dental health of the American public.

How Fluoride Functions in the Body

About 80 to 90% of ingested fluoride is absorbed. Fluoride has a high affinity for calcium, so, when consumed with milk or other high-calcium foods, the fluoride forms an insoluble salt with calcium and absorption is reduced. In the body, fluoride is usually associated with calcified tissues such as bones and teeth. When fluoride is incorporated into the hydroxyapatite crystals of tooth enamel, it makes the enamel more resistant to the acid that causes decay.

Fluoride Deficiency

Adequate dietary fluoride is important for bone and dental health. When fluoride is deficient, tooth decay is more common. Because there are few food sources of fluoride and the fluoride content of water is variable, fluoride supplements or water fluoridation is often needed to minimize dental caries. Ingested fluoride benefits dental health throughout life,[59] but it has its greatest effect on dental caries prevention early in life, during maximum tooth development up to the age of 13. During this time it can be incorporated into tooth enamel, making the enamel more acid resistant.

After the teeth are formed, fluoride is no longer incorporated into the enamel, but fluoride ingested in food, water, and supplements is secreted in saliva, which continually bathes the teeth. This prevents cavities by reducing the amount of acid produced by bacteria, inhibiting the dissolution of tooth enamel by acid, and increasing enamel remineralization after acid exposure. Fluoride in toothpaste and mouth rinses has the same topical effect but only remains in the mouth for a few hours after use.

Fluoride is also incorporated into the mineral crystals in bone. Fluoride supplements stimulate bone formation and increase bone density but there is no clear evidence that fluoride therapy reduces fractures and it may have side effects.[59] The amount of fluoride in drinking water does not affect bone health.[60]

Recommended Fluoride Intake

Epidemiology has confirmed the effectiveness of fluoridated water in reducing dental cavities. The criterion used to establish an AI for fluoride is the estimated intake shown to reduce the occurrence of dental caries maximally without causing unwanted side effects. The AI for fluoride from all sources is set at 0.05 mg per kilogram per day for everyone 6 months of age and older.[52] Thus, for children ages 4 through 8 years, the AI is set at 1.1 mg/day using a reference weight of 22 kg. For adult men ages 19 and older, the AI is 3.8 mg/day based on a weight of 76 kg; for women, it is 3.1 mg/day based on a weight of 61 kg. The AI is not increased during pregnancy or lactation.

Breast milk is low in fluoride, and ready-made infant formulas are prepared with unfluoridated water. Unless infant formula is prepared at home with fluoridated water, it contains little fluoride. The American Academy of Pediatrics recommends the use of fluoridated toothpaste for all children beginning at tooth eruption and suggests a supplement of 0.25 mg of fluoride per day for children 6 months to 3 years of age, 0.5 mg/day for ages 3 to 6 years, and 1.0 mg/day for ages 6 to 16 who are receiving less than 0.3 mg per liter of fluoride in the water supply.[61] These supplements are available by prescription for children living in areas with low water fluoride concentrations. Swallowed toothpaste is estimated to contribute about 0.6 mg/day of fluoride in young children.[52]

Fluoride Toxicity

fluorosis A condition caused by chronic overconsumption of fluoride, characterized by black and brown stains and cracking and pitting of the teeth.

Fluoride can cause adverse effects in high doses. In children, fluoride intakes of 2 to 8 mg/day can cause stained, pitted teeth, a condition called **fluorosis** (Figure 12.24A). The prevalence of fluorosis in the United States has increased recently.[62] This is believed to be due to increased fluoride consumption from fluoride-containing toothpaste, fluoride supplements, and expansion of water fluoridation, which has increased the fluoride content of many processed foods and beverages. In response to the increase in fluorosis, the U.S. Public Health Service has reduced the optimal fluoride concentration it recommends in public drinking water.[53] Due to

FIGURE 12.24 Dental fluorosis

Biophoto Associates/Science Source Images

Dr. P. Marazzi/Science Source Images

A. Too much dietary fluoride causes staining and pitting of the teeth. These photos compare normal teeth (left) and teeth showing enamel fluorosis (right).

© Tamas Panczel - Eross/iStockphoto/

WARNING: Keep out of the reach of children under 6 years of age. If you accidentally swallow more than used for brushing, get medical help or contact a Poison Control Center right away.

B. To help reduce the risk of excess fluoride intake, toothpaste labels must include this warning.

concern over excess fluoride intake, a warning is now required on fluoride-containing toothpastes (Figure 12.24B).

In adults, fluoride doses of 20 to 80 mg/day can result in changes in bone that can be crippling, as well as changes in kidney function and possibly nerve and muscle function. Death has been reported with an intake of 5 to 10 g/day. The UL for fluoride is set at 0.1 mg per kilogram per day for infants and children less than 9 years of age and at 10 mg/day for people ages 9 through 70.[52] Table 12.2 provides a summary of the sources, recommended intakes, functions, deficiencies, and toxicities of fluoride and the other trace minerals.

12.11 Molybdenum (Mo)

LEARNING OBJECTIVE

- Discuss how the molybdenum content of the soil affects the content of food.

Like many other trace elements, molybdenum is needed to activate enzymes. The molybdenum content of food varies with the molybdenum content of the soil where the food is produced. The most reliable sources include milk, milk products, organ meats, breads, cereals, and legumes.

Molybdenum is readily absorbed from foods. The amount in the body is regulated by excretion in the urine and bile. Molybdenum is a cofactor for enzymes necessary for the metabolism of sulfur-containing amino acids and nitrogen-containing compounds that make up the structure of DNA and RNA, the production of uric acid (a nitrogen-containing waste product), and the oxidation and detoxification of various other compounds.

Although molybdenum deficiency in humans has been reported as a result of long-term TPN, a naturally occurring deficiency has never been reported. Deficiency has been induced in

TABLE 12.2 A Summary of the Trace Minerals (All Values Are RDAs Unless Otherwise Noted)

Mineral	Sources	Recommended intake for adults	Major functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
Iron	Red meats, leafy greens, dried fruit, whole and enriched grains	8–18 mg/day	Part of hemoglobin, which delivers oxygen to cells; myoglobin, which holds oxygen in muscle; and electron carriers in the electron transport chain; needed for immune function	Iron deficiency anemia: fatigue, weakness, small pale red blood cells, low hemoglobin	Infants and preschool children, adolescents, women of childbearing age, pregnant women, athletes, vegetarians	Gastrointestinal upset, liver damage	45 mg/day
Zinc	Meat, seafood, whole grains, eggs	8–11 mg/day	Regulates protein synthesis; functions in growth, development, wound healing, immunity, and antioxidant protection	Poor growth and development, skin rashes, decreased immune function	Vegetarians, low-income children, older adults	Decreased copper absorption, depressed immune function	40 mg/day
Copper	Organ meats, nuts, seeds, whole grains, seafood, cocoa	900 μg/day	A part of proteins needed for iron absorption, lipid metabolism, collagen synthesis, nerve and immune function, and antioxidant protection	Anemia, poor growth, connective tissue abnormalities	Those who oversupplement zinc	Vomiting, liver damage	10 mg/day
Manganese	Nuts, legumes, whole grains, tea	1.8–2.3 mg/day[a]	Functions in carbohydrate and lipid metabolism and antioxidant protection	Growth retardation	None	Nerve damage	11 mg/day
Selenium	Organ meats, seafood, eggs, whole grains	55 μg/day	Antioxidant protection as part of glutathione peroxidase, synthesis of thyroid hormones; spares vitamin E	Muscle pain, weakness, Keshan disease	Populations in areas with low-selenium soil	Nausea, diarrhea, vomiting, fatigue, hair and nail changes	400 μg/day
Iodine	Iodized salt, saltwater fish, seafood, dairy products	150 μg/day	Needed for synthesis of thyroid hormones	Goiter, cretinism, intellectual disability, growth and developmental abnormalities	Populations in areas with low-iodine soil and iodized salt is not used	Enlarged thyroid	1110 μg/day
Chromium	Brewer's yeast, nuts, whole grains, mushrooms	25–35 μg/day[a]	Enhances insulin action	High blood glucose	Malnourished children	None reported	ND
Fluoride	Fluoridated water, tea, fish, toothpaste	3–4 mg/day[a]	Strengthens tooth enamel, enhances remineralization of tooth enamel, reduces acid production by bacteria in the mouth	Increased risk of dental caries	Populations in areas with unfluoridated water	Mottled teeth, kidney damage, bone abnormalities	10 mg/day
Molybdenum	Milk, organ meats, grains, legumes	45 μg/day	Cofactor for a number of enzymes	Unknown in humans	None	Arthritis and joint inflammation	2 mg/day

[a]Adequate Intake (AI).

Note: UL, Tolerable Upper Intake Level; ND, not determined due to insufficient data.

laboratory animals by feeding them high doses of the element tungsten, which inhibits molybdenum absorption. The resulting deficiency caused growth retardation, decreased food intake, impaired reproduction, and decreased life expectancy.

Based on the results of molybdenum balance studies, an RDA has been set at 45 μg/day for adults. The RDA is increased for pregnancy and lactation. An AI has been set for infants based on the amount of molybdenum in breast milk.

There are few data on adverse effects of high intakes of molybdenum in humans. A UL of 2000 μg/day has been set based on impaired growth and reproduction in animals.[8]

12.12 Other Trace Elements

LEARNING OBJECTIVE

- Name four essential trace elements for which no RDA or AI has been established.

Many other trace elements are found in minute amounts in the human body. Some of these may be essential for human health, and others, such as lead (see Chapter 15), may be present only as a result of environmental exposure. Arsenic, boron, nickel, silicon, and vanadium have been reviewed by the DRI committee and found to have a significant role in human health.[8] Arsenic is better known as a poison than an essential nutrient, but the organic forms of arsenic that occur in foods are nontoxic. It is hypothesized that arsenic is involved in the conversion of the amino acid methionine into compounds that affect heart function and cell growth. Arsenic deficiency has been correlated with nervous system disorders, blood vessel diseases, and cancer. Boron may be involved in vitamin D and estrogen metabolism. Nickel is thought to function in enzymes involved in the metabolism of certain fatty acids and amino acids, and it may play a role in folate metabolism. Silicon, the primary constituent of sand, is involved in the synthesis of collagen and the calcification of bone. Vanadium has been shown to have an insulin-like action and to stimulate cell proliferation and differentiation. Data for establishing an AI or an RDA for any of these elements is insufficient, but ULs have been set for boron, nickel, and vanadium.

Other trace elements that have a physiological role include aluminum, bromine, cadmium, germanium, lead, lithium, rubidium, and tin. The specific functions of these have not been defined, and they have not been evaluated by the DRI committee. All the minerals, both those known to be essential and those still being assessed for their role in human health, can be obtained by choosing a variety of foods from each of the food groups of MyPlate.

OUTCOME

About a year after Nissi was diagnosed with goiter, the Indian government began promoting the use of salt fortified with iodine and banned the production and sale of noniodized salt. Nissi's family and many others in the village are now using iodized salt. Nissi has grown to be an energetic teenager, with no trace of goiter.

Some families in Nissi's village still resist using the new salt, but information and education programs are spreading the message that iodized salt is safe and affordable and that it helps children to achieve their full intellectual capacity. The incidence of iodine deficiency continues to drop.

In the United States, where the diet includes food from many locations, the mineral content of the soil is unlikely to affect the risk of nutrient deficiency. However, in Nissi's village where the only affordable food is locally grown, the risk of deficiency is greater. **Without being able to introduce high-iodine foods from other locations, iodine fortification was needed to solve the problem.**

SUMMARY

12.1 Trace Minerals in Our Diet

- Trace minerals are required by the body in an amount of 100 mg or less per day or present in the body in an amount of 0.01% or less of body weight. They include iron, zinc, copper, manganese, selenium, iodine, chromium, fluoride, and molybdenum.

12.2 Iron (Fe) Sources and Functions

- Iron is found in both plant and animal foods. Heme iron is an easily absorbable form that is found in animal products. Nonheme iron, which is less well absorbed, comes from both animal and plant sources.
- The amount of iron that is absorbed from the diet depends on the type of iron and the presence of other dietary components. Heme iron is better absorbed than nonheme iron. The absorption of nonheme iron can be increased by consuming it with meat, vitamin C, or other acids; its absorption is decreased by consuming it with foods containing fiber, phytates, oxalates, and tannins.
- Iron homeostasis is regulated at the intestine. If iron stores are low, more iron is transferred from the mucosal cells to the blood and bound to transferrin for transport to body cells. When body stores are high, less iron is transported from the mucosa into the blood and more is bound to ferritin and lost when mucosal cells die.
- Iron functions as part of hemoglobin, which transports oxygen in the blood, and myoglobin, which enhances the amount of oxygen available during muscle contraction. Iron is also a component of proteins involved in ATP production and is needed for activity of the antioxidant enzyme catalase.

12.3 Meeting Iron Needs

- Iron deficiency is the most common nutritional deficiency worldwide. When iron is deficient, adequate hemoglobin cannot be made, resulting in iron deficiency anemia, which is characterized by small, pale red blood cells.
- The RDA for iron for women ages 19 to 50 is 18 mg/day, more than double the RDA of 8 mg/day for adult men and postmenopausal women.
- Iron can be toxic. Ingestion of a single large dose can be fatal. The accumulation of iron in the body over time causes heart and liver damage and contributes to diabetes and cancer. The most common cause of chronic iron overload is hemochromatosis, a genetic disorder in which too much iron is absorbed.
- Both the amount and bioavailability of dietary iron must be considered when planning a diet to meet iron needs. Supplements are often recommended to groups at risk of deficiency, such as small children, women of childbearing age, and pregnant women.

12.4 Zinc (Zn)

- Good sources of zinc include red meats, eggs, dairy products, and whole grains. Zinc from animal sources is better absorbed than that from plant foods. Phytates inhibit zinc absorption from many plant sources.
- Zinc absorption is regulated by zinc transport proteins that determine how much zinc is moved into and out of the mucosal cell and by metallothionein, a protein that binds zinc in the mucosal cell. When zinc intake is high, more metallothionein is synthesized and zinc absorption is limited.
- Zinc is needed for the activity of many enzymes, including a form of the antioxidant enzyme superoxide dismutase and enzymes that function in the synthesis of proteins, DNA, and RNA; in carbohydrate metabolism; and in acid–base balance. Many of the functions of zinc are related to its role in gene expression. Zinc is needed for tissue growth and repair, development of sex organs and bone, and proper immune function.
- Zinc deficiency results in poor growth, delayed sexual maturation, skin changes, hair loss, skeletal abnormalities, and depressed immunity.
- The RDA for zinc is 11 mg/day for adult men and 8 mg/day for adult women.
- Since copper binds more tightly to metallothionein than zinc, an excess of zinc, which stimulates metallothionein synthesis, can trap copper in the mucosal cells, causing a copper deficiency.
- When administered within 24 hours of the onset of common cold symptoms, supplemental zinc in lozenge form can reduce the duration of cold symptoms.

12.5 Copper (Cu)

- Good sources of copper in the diet include organ meats, seafood, nuts, and seeds.
- The absorption of copper is affected by the presence of other minerals in the diet. The zinc content of the diet can have a major impact on copper absorption.
- Copper functions in a number of important proteins that affect iron and lipid metabolism, synthesis of connective tissue, and antioxidant protection. Copper is transported in the blood bound to proteins such as ceruloplasmin.
- A copper deficiency can cause anemia and connective tissue abnormalities. Copper toxicity from dietary sources is extremely rare.
- The RDA for copper for adults is 900 μg/day.

12.6 Manganese (Mn)

- Good dietary sources of manganese include whole grains and nuts. The AI is 2.3 mg/day for men and 1.8 mg/day for women.
- Manganese is necessary for the activity of some enzymes, including a form of the antioxidant enzyme superoxide dismutase. Manganese is involved in amino acid, carbohydrate, and lipid metabolism.

12.7 Selenium (Se)

- Excellent dietary sources of selenium include seafood, eggs, and organ meats. The selenium content of plant foods depends on the selenium content of the soil where they are grown, and the selenium content of animal products is affected by the amount of selenium in their feed.
- Selenium protects against oxidative damage as an essential part of the enzyme glutathione peroxidase. Glutathione peroxidase destroys peroxides before they can form free radicals. Adequate dietary selenium reduces the need for vitamin E.
- Severe selenium deficiency is rare except in regions with very low soil selenium content and limited diets. In China, selenium deficiency contributes to the development of a heart condition known as Keshan disease. Low selenium intake has been linked to increased cancer risk.

- The RDA for selenium for adults is 55 μg/day.
- Very high selenium intake (5 mg/day) causes fingernail changes and hair loss.
- Selenium supplements are marketed with claims that they will protect against environmental pollutants, prevent cancer and heart disease, slow the aging process, and improve immune function. Supplements that increase intake above the RDA do not provide additional benefits and could have adverse effects.

12.8 Iodine (I)

- The best sources of iodine in the diet are seafood, foods grown in or near the sea, and iodized salt.
- Iodine is an essential component of thyroid hormones, which promote protein synthesis and regulate basal metabolic rate, growth, and development.
- When iodine is deficient, continued release of thyroid-stimulating hormone causes the thyroid gland to enlarge, forming a goiter. Iodine deficiency during pregnancy causes a condition in the offspring known as cretinism, which is characterized by growth failure and developmental disability. Iodine deficiency during childhood and adolescence can impair cognitive function. Iodized salt has virtually eliminated iodine deficiency in North America. Although salt iodization is being used successfully worldwide to prevent iodine deficiency, iodine deficiency remains a world health problem.
- The RDA for iodine in adult men and women is 150 μg/day.
- Acute toxicity can occur with very large doses of iodine. Chronically high intakes of iodine can cause an enlargement of the thyroid gland that resembles goiter.

12.9 Chromium (Cr)

- Chromium is found in liver, brewer's yeast, nuts, and whole grains.
- Chromium is needed for normal insulin action and glucose utilization.
- Overt chromium deficiency is not a problem in the U.S. population.
- Recommended chromium intake is 35 μg/day for men and 25 μg/day for women.
- Chromium supplements are marketed to control blood sugar and increase lean body mass. Controlled trials have reported no dietary chromium toxicity in humans.

12.10 Fluoride (F)

- Most of the fluoride in the diet in the United States comes from fluoridated drinking water and toothpaste.
- Fluoride is necessary for the maintenance of bones and teeth. Adequate dietary fluoride helps prevent dental caries in children and adults.
- Low fluoride intake increases the risk of dental caries. Excess fluoride causes dental fluorosis in children.
- The recommended fluoride intake from all sources is set at 0.05 mg per kilogram per day for everyone 6 months of age and older because it protects against dental caries with no adverse effects.

12.11 Molybdenum (Mo)

- Molybdenum is a cofactor for enzymes involved in the metabolism of the amino acids methionine and cysteine and nitrogen-containing compounds such as DNA and RNA.

12.12 Other Trace Elements

- There is evidence that boron, arsenic, nickel, silicon, and vanadium may be essential in humans as well as animals. These elements may be necessary in small amounts, but can be toxic if consumed in excess.

FOCUS ON Dietary Supplements

© Selahattin Gezer/iStockphoto

CHAPTER OUTLINE

FOCUS 4.1 **What Is a Dietary Supplement?**
Dietary Supplement Labels
Regulation of Dietary Supplements

FOCUS 4.2 **Nutrient Supplements**
Vitamins and Minerals
Supplemental Carbohydrate
Protein and Amino Acid Supplements
Supplements of Omega-3 Fatty Acids

FOCUS 4.3 **Substances Made in the Body**
Enzyme Supplements
Hormone Supplements
Coenzyme Supplements
Supplements Containing Structural and Regulatory Molecules

FOCUS 4.4 **Phytochemical Supplements**
Carotenoids
Flavonoids

FOCUS 4.5 **Herbal Supplements**
Ginkgo Biloba
St. John's Wort
Ginseng
Garlic
Echinacea
Saw Palmetto
Kava

If you are looking for a dietary supplement, you won't have to look far. There are thousands of different products from which to choose. They come as tablets, capsules, powders, gummi chews, gelcaps, and liquids. They are sold in health food stores, supermarkets, drug stores, and national discount chain stores, as well as through mail-order catalogs, television, the Internet, and direct sales. Most of these products contain vitamins and minerals, but many contain other nutrients, such as protein, amino acids, or fatty acids. Others contain substances that are not classified as nutrients at all, such as hormones, enzymes, and coenzymes, which are made in the body but are not dietary essentials. Some contain plant-derived substances such as phytochemicals and herbs. A recent survey suggests that 68% of American adults take dietary supplements, and over 17% use nonvitamin/nonmineral supplements.[1,2] They are

taken to improve athletic performance, promote weight loss, prevent and treat disease, slow aging, and for a variety of other reasons. For many supplements, there is scientific evidence of beneficial effects. **For others, the benefits are more questionable, and for a few, the risk of using them clearly outweighs any benefits they may provide.**

F4.1 What Is a Dietary Supplement?

LEARNING OBJECTIVES

- List the types of substances that are included in dietary supplements.
- Explain the regulatory impact of classifying dietary supplements as foods, rather than drugs.

The term *dietary supplement* traditionally referred to products designed to add essential nutrients to the diet. But the 1994 Dietary Supplement Health and Education Act (DSHEA) broadened this definition to include any product intended for ingestion as a supplement to the diet. These products can include vitamins and minerals, as well as herbs and other plant-derived substances, amino acids and concentrates, metabolites, constituents, and extracts of these substances. People take them for a variety of reasons—weight loss, enhanced athletic performance, antioxidant protection. For example, if you were looking for a weight-loss supplement, you could find one that contains nutrients, or herbs, or a variety of other substances (**Table F4.1**).

Just because a product is sold as a supplement does not mean that it is safe or effective. Unlike most foods, dietary supplements may contain amounts of nutrients and other substances that exceed levels normally found in the diet and may therefore present a risk, particularly for people taking medications or with certain medical conditions. Unlike drugs, dietary supplements are not strictly regulated in terms of dose or constituents.

Dietary Supplement Labels

Products sold as dietary supplements must carry a standard label that meets the specifications of the DSHEA.[3] According to FDA regulations, any product intended for ingestion as a supplement to the diet must include the words "dietary supplement" on the label and carry a "Supplement Facts" panel (**Figure F4.1** and Chapter 2). The Supplement Facts panel lists the recommended serving size and the name and quantity of each ingredient per serving. The nutrients for which Daily Values have been established are listed first, followed by other dietary ingredients for which Daily Values have not been established.[3]

To ensure that dietary supplements do not contain contaminants and that the information listed on the supplement label is accurate, the FDA has established regulations regarding current Good Manufacturing Practices (cGMP) for dietary supplements.[4] These require manufacturers to evaluate their products for identity, purity, strength, and composition. The U.S. Pharmacopeia (USP) has also developed a voluntary dietary supplement verification program. Those manufacturers who participate in the program can include the USP-verified mark on their product label (see Chapter 2, Figure 2.13).

Regulation of Dietary Supplements

Although dietary supplements are often taken as drugs to prevent or treat disease, their safety and marketing are not regulated as strictly as drugs. Drugs are required to undergo testing that must be reviewed by the FDA before they can be marketed to the public. This is not the case for supplements. Most do not require FDA approval before they are sold. Supplement manufacturers are responsible for ensuring product safety. If a problem arises with a specific product, the FDA must prove that the supplement represents a risk before it can be removed from the market. The exception to this rule is products that contain new ingredients. The manufacturer of any supplement containing an ingredient not sold in the United States before October 15, 1994, must provide the FDA with safety data prior to marketing the product. Ingredients sold prior to this date are presumed safe based on their history of use by humans.[3]

TABLE F4.1 Examples of Supplements Sold to Promote Weight Loss

Supplement	Proposed action	Effectiveness and safety
Apple cider vinegar	Increases energy expenditure, reduces hunger and food cravings.	Safe, but no evidence that it has any effect on body weight.
Bitter orange	Increases energy expenditure.	May promote short-term weight loss. May increase the risk of hypertension, arrhythmias, heart attacks, strokes, and seizure.
Cascara, senna, aloe, buckthorn, rhubarb root, and castor oil	Increase water loss.	Do not cause fat loss, and overuse can cause diarrhea, vomiting, stomach cramps, chronic constipation, fainting, and severe electrolyte imbalances.
Chitosan	Blocks fat absorption.	Has not been shown to enhance weight loss. Short-term human trials have not reported any severe adverse effects. No long-term studies have been done.
Chromium	Affects carbohydrate metabolism.	Human trials have not demonstrated an effect on body composition or body weight. Few reports of adverse effects in humans.
Conjugated linoleic acid (CLA)	Increases fat oxidation or reduces fat synthesis.	No evidence that it is effective for weight loss in humans. It causes gastrointestinal symptoms.
Country mallow	Increases energy expenditure.	May promote short-term weight loss. May increase the risk of hypertension, arrhythmias, heart attacks, strokes, and seizure.
Dandelion	Increases water loss.	Upset stomach, diarrhea, allergic reactions.
Ephedra (ma huang, Chinese ephedra)	Increases energy expenditure.	May promote short-term weight loss but increases the risk of high blood pressure, irregular heartbeat, heart attack, stroke, and death.
Ginseng	Affects carbohydrate metabolism.	No evidence that it enhances weight loss. Side effects include diarrhea, headache, insomnia, changes in blood pressure, and altered bleeding time.
Glucomannan	Increases satiety.	Safe, but has not been shown to promote weight loss.
Green tea	Increases fat oxidation or reduces fat synthesis.	Safe, but no evidence from controlled clinical trials that tea or tea extracts promote weight loss.
Guar gum	Increases satiety.	Safe, but has not been shown to promote weight loss.
Guarana	Suppresses appetite.	Contains caffeine (about twice as much as coffee beans) and has been shown to be effective for short-term weight loss when used in combination with ephedra. Side effects include anxiety, nervousness, and difficulty sleeping.
Guggul	Boosts metabolism by stimulating thyroid activity.	No human studies support the claim that it boosts thyroid activity. Side effects include gastrointestinal upset, headache, nausea, and hiccups.
Hoodia (kalaharii cactus, xhoba)	Suppresses appetite.	Safety unknown. No reliable scientific evidence to support its effectiveness.
Hydroxycitric acid (extract from *Garcinia cambogia*)	Increases fat oxidation or reduces fat synthesis.	Not found to be effective. Side effects include a laxative effect, abdominal pain, and vomiting.
L-Carnitine	Increases fat oxidation.	Not found to significantly affect total body mass or fat mass. Side effects include nausea, vomiting, abdominal cramps, diarrhea, and body odor.
Licorice	Increases fat oxidation or reduces fat synthesis.	Has been shown to reduce body fat in normal-weight subjects, but causes high blood pressure and low blood potassium.
Psyllium	Increases satiety.	Safe, but has not been shown to promote weight loss.
Pyruvate	Increases fat oxidation or reduces fat synthesis.	Some studies have shown a weight-loss benefit in individuals on weight-loss diets, but the dosage used in the studies was very high. No known side effects.
Spirulina (blue-green algae)	Suppresses appetite.	Safe, but no evidence that it aids weight loss.
St. John's wort	Enhances mood.	No evidence it promotes weight loss. Contains similar ingredients to the antidepressant drug fluoxetine (Prozac) and should not be used by people taking antidepressants.

FIGURE F4.1 Supplement Facts labels
This Supplement Facts panel from a supplement marketed to reduce appetite and aid in weight loss indicates that it contains vitamins, as well as amino acids, plant extracts, and some substances made in the body.

Supplement Facts

Serving Size: 2 Capsules
Servings Per Container: 60

	Amount Per Serving	DV%
Vitamin C (as ascorbic acid)	60mg	100%
Pantothenic Acid (as calcium pantothenate)	20mg	200%
Vitamin B_6 (as pyridoxine HCL)	8mg	400%
Niacin	5mg	25%
Folate (as folic acid)	100mcg	25%
Zinc (as zinc gluconate)	5mg	33%
Copper (as copper gluconate)	500mcg	25%
NADH (Nicotinamide Adenine Dinucleotide)	1000mcg	*
Hoodia Gordonii Extract (20:1 Extract-Equal to 2000 mg of whole plant)	100mg	*
5-Hydroxytryptophan (Griffonia Simplicifolia)	25mg	*
N, N Dimethylglycine	50mg	*
Trimethylglycine	75mg	*
L-Phenylalanine	600mg	*
Decaffeinated Green Tea Extract (Total Catechins 130mg, Epigaliocatechin Galiate (EGCG) 70mg)	175mg	*
Salvia Scalarea Extract	50mg	*
Choline (as bitartrate)	75mg	*

*Daily Value (DV, not established)

Recommended Use: As a dietary supplement take two capsules before breakfast on an empty stomach (or before exercise) and two capsules at mid-afternoon preferably with 8 oz of water.

This supplement includes a variety of vitamins and minerals. Do the amounts of any exceed 100% of the Daily Value? Do the amounts of any exceed the UL?

This supplement contains many ingredients that are not vitamins or minerals and therefore have no Daily Value or UL. Are they safe when taken in these amounts?

F4.2 Nutrient Supplements

LEARNING OBJECTIVES

- List some reasons vitamin/mineral supplements may be necessary.
- Explain the rationale for supplementing carbohydrate.
- Compare the benefits and risks of protein and amino acid supplements to those of dietary protein.
- Discuss why food is recommended over supplements as a source of omega-3 fatty acids.

A varied balanced diet will meet nutrient needs for most healthy people (see Chapter 9). However, some people choose to supplement specific nutrients because they don't think they get enough in their diets, or because they are looking for additional beneficial effects, such as disease prevention or performance enhancement.

Vitamins and Minerals

Multivitamin/mineral supplements are the most commonly used dietary supplements.[5] Despite this, there is little evidence that they help to prevent chronic disease, a reason many people choose to take these supplements. Most healthy adults who consume a reasonably good diet do not need supplements and can meet their nutrient needs by eating a varied diet.[6] However, individuals who have increased needs due to life stage or illness, those whose nutrient absorption is reduced, and those with excess losses may need supplements (see Chapter 9). The benefits and risks of individual vitamin and mineral supplements are discussed with each nutrient in Chapters 8 through 12.

Supplemental Carbohydrate

Despite the popularity of diets low in carbohydrate, carbohydrate supplements are frequently used by athletes. Carbohydrate pills can't provide enough carbohydrate to have a significant

Andy Washnik

FIGURE F4.2 Supplements providing omega-3 fatty acids
Fish oil and flaxseed oil supplements can increase your omega-3 fatty acid intake, but do not provide all the health benefits of eating a diet that includes fish and flaxseeds.

effect, so supplemental carbohydrate usually comes in the form of sports beverages, bars, or carbohydrate gels. These are packaged for convenience and easy transport, and the carbohydrate is in a form that is absorbed from the GI tract quickly to provide glucose to exercising muscles (see Chapter 13).

Protein and Amino Acid Supplements

Protein supplements are also popular with athletes (see Chapters 6 and 13). They generally come as powders, drinks, and bars. They provide no benefit beyond that obtained from the protein in an adequate diet. Individual amino acids are also marketed for their effect on performance and body composition and therefore are popular among athletes and dieters. The amino acids arginine, ornithine, and lysine are taken because they have been found to stimulate the release of growth hormone, which promotes muscle growth. Therefore, these are promoted to people who want to build muscle and lose fat. However, controlled studies have found that oral supplements of these amino acids taken before exercise do not significantly boost growth hormone release, or increase muscle mass or strength above that obtained from training alone.[7] Branched-chain amino acids (leucine, isoleucine, and valine) are marketed to athletes to improve athletic performance and aid in recovery from strength exercise. Although studies examining branched-chain amino acid supplements have not found them to enhance performance, there is evidence that they may have some benefits in improving muscle recovery and preventing muscle soreness after intense exercise.[8] Glutamine and glycine supplements are also marketed to athletes, but neither has been found to enhance exercise performance. Adequate amounts of amino acids can be obtained from whole-food sources of protein, without amino acid supplements. Because some amino acids share transport systems, supplementing one amino acid can cause a deficiency of others that use that same transport system (see Chapter 6).

Supplements of Omega-3 Fatty Acids

Supplements of omega-3 fatty acids from fish oils and flaxseed are taken to reduce the risk of heart disease (Figure F4.2). Scientific evidence shows that the long-chain omega-3 fatty acids EPA and DHA protect against heart disease, but supplements may not be as beneficial as food sources of these fatty acids.[9] Eating fish has been found to provide greater health benefits than taking fish oil supplements.[10] Flaxseed oil provides α-linolenic acid. To have heart-protective effects, this needs to be converted into the longer-chain omega-3 fatty acids, EPA and DHA (see Chapter 5). Because the conversion of α-linolenic acid to EPA and DHA is inefficient in humans, flaxseed oil supplements do not provide as much EPA and DHA as fish oil.[9] However, consuming the entire flaxseed, rather than just the oil, adds not only omega-3 fatty acids, but also fiber and phytochemicals to the diet. Eating fish several times a week and sprinkling ground flaxseed on your cereal may be a better option than taking supplemental oils. The risks of taking supplements containing omega-3 fatty acids are minimal for healthy people, but these products are not recommended for those taking blood-thinning medications because they inhibit blood clotting.

F4.3 Substances Made in the Body

LEARNING OBJECTIVES

- Discuss why most enzyme supplements are ineffective.
- Describe the benefits of popular hormone supplements.

Many molecules essential to normal metabolic and physiological function are made in the body in amounts sufficient to meet needs and are therefore not essential in the diet. No deficiency symptoms occur when they are absent from the diet. Nonetheless, supplements of many of these

biological molecules are sold to enhance body functions. Most of these provide little benefit to healthy, well-nourished individuals.

Enzyme Supplements

Enzymes are proteins. Those needed for normal function are made in the body. When consumed in supplements, like other proteins, they are broken down into amino acids in the GI tract. The enzyme protein itself never reaches cells inside the body, and therefore most enzyme supplements have little effect on body function (see Chapter 6). The exception to this is digestive enzymes that act in the gastrointestinal tract. When supplemented, these can perform their functions before they are broken down. For example, lactase, the enzyme that breaks down the milk sugar lactose, can benefit individuals with lactose intolerance when consumed along with foods containing lactose. The enzyme breaks down lactose that is in the GI tract. Eventually the lactase is also digested.

A number of other digestive enzymes, including proteases, lipases, amylases, and plant enzymes, such as bromelain from pineapple and papain from papaya, are marketed to improve digestion in normal, healthy people. Advertisements for these products claim that the digestive enzymes naturally present in food are destroyed by cooking, leaving partially digested substances in the GI tract and forcing the body to synthesize more of its own digestive enzymes. Despite the popularity of enzyme supplements, there is no evidence that they are beneficial for healthy people.

Hormone Supplements

Hormones are powerful regulatory molecules. Whether hormone supplements have any effect depends on whether they can be absorbed intact. Peptide hormones such as growth hormone are made of chains of amino acids so they have the same problem as enzymes—they are broken down in the gut before they can reach their target and thus cannot function as hormones in the body. Despite this, oral growth hormone supplements are sold. Growth hormone is appealing to athletes because it increases muscle protein synthesis. Despite this physiological effect, even growth hormone injections, which are the only way to get the active hormone into the body, have not been shown to enhance muscle strength, power, or aerobic exercise capacity, although there is evidence that they improve anaerobic exercise capacity.[11]

Hormones that are not proteins can be absorbed into the body intact and supplemental doses may affect body functions (Figure F4.3). Melatonin is a hormone made by the pineal gland in the brain. Although it is synthesized from the amino acid tryptophan, it is not a protein and supplemental doses can be absorbed intact from the GI tract. Supplements of melatonin are taken to delay aging, protect against free radical damage, and help with sleep disorders and jet lag. There is little evidence that it slows the aging process or that it reduces oxidative damage, but there is significant evidence linking the hormone melatonin to sleep cycles in humans. It has been suggested that in situations where the body's production of melatonin is reduced or the normal sleep/wake cycle is disrupted, such as with jet lag, supplemental melatonin may improve both sleep duration and quality. Melatonin may help to decrease jet lag symptoms and hasten the return to normal energy levels. Melatonin may also shorten the time it takes for people with insomnia to fall asleep, but it does not appear to improve sleep quality in people whose jobs require them to work on rotating shift schedules.[12]

Like melatonin, steroid hormones can be absorbed in the digestive tract and reach the bloodstream intact, thereby affecting function. DHEA (dehydroepiandrosterone), a steroid hormone made by the adrenal glands, is a popular supplement. It is a precursor to the sex hormones estrogen and testosterone. The production of DHEA in the body peaks in one's mid-twenties, and gradually declines with age in most people. Preventing this drop has been suggested to delay the aging process by maintaining levels of estrogen and testosterone. It has been claimed that DHEA improves energy level, strength, and immunity. Athletes use it as a substitute for anabolic steroids to increase muscle mass and decrease body fat. However, supplementation has not been found effective in increasing muscle size or strength or in

Andy Washnik

FIGURE F4.3 Melatonin and DHEA
Melatonin and DHEA are hormones that can be purchased in supplement form. DHEA use is banned by the International Olympic committee, the National College Athletic Association, and most major league sporting organizations.

treating the symptoms of advancing age, male sexual dysfunction, or menopause.[13] The long-term effects of DHEA supplements have not been studied, but there is concern that they may interfere with normal levels of the sex hormones and have detrimental effects on the body, including liver damage.

Coenzyme Supplements

Many vitamins have coenzyme functions, but there are also coenzymes that are not dietary essentials. One of these is lipoic acid, which is a coenzyme needed for two reactions necessary for the production of ATP by aerobic metabolism. Although essential to energy metabolism, lipoic acid can be synthesized in adequate amounts by human cells, so supplements do not accelerate the reactions catalyzed by this coenzyme.

Ubiquinone, also called *coenzyme Q* is another coenzyme important for the production of ATP from carbohydrate, fat, and protein. It is needed in the electron transport chain, the final stage of aerobic metabolism where ADP is converted to ATP. Because, as its name implies, it is present ubiquitously in animals, plants, and microorganisms, and is synthesized in the human body, supplements are not necessary for most people. However, supplements may be beneficial in individuals with inherited defects that affect coenzyme Q synthesis.[14] Low levels of coenzyme Q are also a concern in those taking cholesterol-lowering statin drugs such as Crestor and Lipitor. Statins inhibit an enzyme needed for the synthesis of both cholesterol and ubiquinone, which can cause depletion of this coenzyme. Depletion of coenzyme Q in the mitochondria of muscle cells has been suggested to be a cause of the muscle pain and weakness that appears as a side effect in some individuals taking statins. An analysis of available randomized controlled trials found coenzyme Q supplementation to have little effect on the muscle pain and weakness in patients taking statin drugs.[15]

Supplements Containing Structural and Regulatory Molecules

A number of structural and regulatory molecules are taken as supplements for a variety of different reasons. For instance, carnitine and creatine are both sold to enhance athletic performance (see Chapter 13). Carnitine is a molecule that is needed to transport fatty acids into the mitochondria, where they are broken down by β-oxidation and aerobic metabolism to produce ATP. Supplements are marketed to increase endurance by improving the use of fat as an energy source during exercise. Supplements have not been shown to improve endurance.[16] Creatine is a small nitrogen-containing molecule found primarily in muscle, where it is used to make a high-energy molecule called creatine phosphate. Creatine phosphate provides energy to the muscle for short bursts of activity. Creatine supplementation, when combined with strength training, has been shown to increase strength, power, and muscle mass more than strength training alone. Creatine supplements have the greatest benefit for short-duration high-intensity intermittent exercise lasting 30 seconds or less (see Chapter 13).[17]

Glucosamine, chondroitin, and SAM-e are molecules needed for the maintenance of healthy joints and are sold to alleviate the pain and progression of osteoarthritis. Glucosamine and chondroitin are molecules found in and around the cells of cartilage, the type of connective tissue that cushions joints. They are made in the body and consumed in the diet in meat. Supplements of both glucosamine and chondroitin are reported to reduce arthritis pain, stop cartilage degeneration, and possibly stimulate the repair of damaged joint cartilage (**Figure F4.4**). Clinical studies on the effect of these supplements on pain and function have been equivocal (see Chapter 16).[18]

Andy Washnik

FIGURE F4.4 Glucosamine and chondroitin sulfate supplements
People suffering from arthritis commonly take supplements containing glucosamine and chondroitin sulfate in the hope that they will reduce pain. The pills are large and about three a day are recommended. They are safe to take, but do not consistently reduce symptoms or improve joint structure.[18]

SAM-e, chemically known as S-adenosylmethionine, is present in the body normally as an intermediate in the metabolism of the amino acid methionine. SAM-e enhances the production of cartilage, and supplements are promoted for the treatment of arthritis. It may be as effective as aspirin and similar medications for treating the symptoms of arthritis, but takes longer to have an effect.[19] Data also suggests that SAM-e supplementation reduces the symptoms of depression; it may be as effective as prescription antidepressants in some cases. Anyone taking SAM-e in combination with a prescription antidepressant should be monitored by a health professional.[19]

Supplements of inositol can also be found on the shelf. Inositol is a component of phospholipids in cell membranes, where it plays a role in relaying messages to the inside of the cell. Inositol can be synthesized from glucose. There is no evidence that it is essential in the human diet, but it may have some clinical value in treating diseases such as diabetes and kidney failure and preventing the side effects of cancer treatment.[20,21]

F4.4 Phytochemical Supplements

LEARNING OBJECTIVES

- Explain why phytochemical supplements may not have the same benefits as foods containing these phytochemicals.
- Discuss how phytochemical supplements may affect antioxidant levels in the body.

A diet rich in phytochemicals from fruits, vegetables, and whole grains has been shown to reduce the risk of heart disease and cancer (see Focus on Phytochemicals). Although we have not yet isolated and identified all of these health-promoting substances, some have been extracted, purified, and pressed into pills or capsules. These are advertised as having health-promoting properties, but they do not appear to provide all the benefits obtained from whole foods that are rich sources of these as well as a host of other phytochemicals and nutrients.

Carotenoids

Carotenoids are a group of more than 600 yellow, orange, and red compounds found in living organisms. Carotenoids have antioxidant properties, and some also have vitamin A activity. The most prevalent carotenoids in the North American diet include *ß*-carotene, *α*-carotene, *ß*-cryptoxanthin, lycopene, lutein, and zeaxanthin. The major sources of carotenoids in the diet are fruits and vegetables (Figure F4.5).

Lutein and zeaxanthin are carotenoids found in leafy green vegetables. They do not have vitamin A activity but are concentrated in the macula of the eye, where they protect against oxidative damage. The effect of these carotenoids on the incidence and progression of the age-related eye disorder, macular degeneration, is equivocal (see Chapter 16).[22]

ß-Carotene supplements are marketed for their antioxidant properties, but under some circumstances *ß*-carotene may promote rather than prevent oxidative damage. One explanation for the increase in the incidence of lung cancer among smokers supplemented with *ß*-carotene is that pro-oxidant activity prevails over antioxidant activity.[23] Because supplements do not provide the same amounts and variety of phytochemicals and other substances found in foods, their effect is sometimes unpredictable.

Flavonoids

Like carotenoids, flavonoids, which are often called bioflavonoids, are antioxidants. Supplements containing categories of flavonoids such as rutin and hesperidin and the flavonoid complex pycnogenol are advertised as cures for arthritis, heart disease, high blood pressure, and colds. Hesperidin is often called vitamin P, but it does not meet the definition of a vitamin because it has not been shown to be essential in the diet. Bioflavonoids are often included in supplements containing vitamin C because they are purported to promote the action of this vitamin. Although the foods containing these phytochemicals have been shown to have health-promoting properties, supplements have not been shown to have the same health effects.

Andy Washnik

FIGURE F4.5 Foods rich in carotenoids
Fruits and vegetables provide most of the carotenoids in our diet.

F4.5 Herbal Supplements

LEARNING OBJECTIVES

- Explain why people choose to take herbal supplements.
- Compare the risks and benefits of herbal supplements.

Twenty-three percent of supplement users take botanicals.[24] The term *botanical* refers to a plant or plant part valued for its medicinal or therapeutic properties. Herbs are a type of botanical. Throughout history, folk medicine has used herbs to prevent and treat disease. Today, herbs and herbal supplements are more popular than ever. It is estimated that about one in six Americans uses herbs to treat maladies or boost health.[25]

Herbal supplements are readily available and relatively inexpensive. They can be purchased without a trip to the doctor or a prescription. Although consumers who want to manage their own health may view this as beneficial, it can also cause problems. When a drug is prescribed by a physician, it is assumed that it will have a beneficial effect, that each dose will contain the same amount of drug, that the physician or pharmacist has considered other medications and other medical conditions that may alter the effectiveness of the drug, and that the drug itself will cause no severe side effects. These assumptions cannot be made with herbs. Many botanical compounds are toxic, either alone or in combination with drugs and other herbs being consumed; the FDA has issued warnings about ingredients such as black cohosh and kava, and it took ephedra off the market.[26] Because herbal products are made from unpurified plant material, there is also a risk of contamination with pesticides, microbes, metals, and other toxins.[27] And it is difficult to know what dose of an herb you are taking. Even those pressed and packaged into pills may not provide the same dose in each pill. Also, because consumers decide what to treat, herbal remedies can be used inappropriately or instead of necessary medical intervention.

Some herbs may offer benefits, but serious side effects from excessive doses or unusual combinations of herbs and medications are not uncommon. The use of herbal supplements also may be inappropriate at certain times. For example, St. John's wort can prolong and intensify the effects of narcotic drugs and anesthetic agents, so it should not be taken for two to three weeks prior to surgery. Herbal products should also be avoided during pregnancy. Blue cohosh (used to treat menstrual cramps), juniper (used for heartburn), pennyroyal or rosemary (used for digestive problems), sage (used for stomach upset), and thuja (used for respiratory infections), and even raspberry tea (used to treat morning sickness) may stimulate uterine contractions, which can increase the risk of miscarriage or premature labor.[28] Some guidelines to follow if you are considering taking herbs or herbal supplements are included in Table F4.2.

Ginkgo Biloba

Ginkgo biloba, also called "maidenhair," is one of the top-selling herbal medicinal products in the United States (Figure F4.6A). It has been used for millennia in Chinese medicine to treat asthma

TABLE F4.2 Considerations When Choosing Herbal Supplements

- If you are ill or taking medications, consult your physician before taking herbs.
- If you are pregnant consult your physician before taking herbs.
- Do not give herbs to children.
- Do not assume herbal products are safe.
- Do not take herbs with known toxicities.
- Read label ingredients and the list of precautions.
- Start with low doses, and stop taking any product that causes side effects.
- Do not take combinations of herbs.
- Do not use herbs for long periods.
- Do not choose products that claim to be a secret cure, and be wary of terms such as "breakthrough," "magical," "miracle cure," and "new discovery."

FIGURE F4.6 Herbal supplements
Herbal supplements are derived from plants, many of which are common in fields, gardens, or kitchens.

Altrendo/Getty Images, Inc.

A. The leaves of the *Ginkgo biloba* plant are used to make the top-selling herbal supplement in the United States.

Michael Gadomski/Photo Researchers

B. These yellow flowers of St. John's wort grow wild in fields and pastures and are considered a perennial weed.

Lynn Johnson/NG Image Collection

C. Ginseng capsules, extracts, and powders are made from the dried root of the ginseng plant.

© Christine Glade/iStockphoto

D. Garlic is used to spice food in the kitchen, but extracts are also processed into pills or tablets and marketed as herbal supplements.

Linda Lewis/Botanica/Getty Images

E. Flowers of the echinacea plant, like the ones shown here, can be seen growing along the roadside in the western United States.

© William Mullins/Alamy Limited

F. Saw palmetto (*Serenoa repens*) is the dominant ground cover in some pine forests in Florida, Louisiana, and North Carolina.

and skin infections, but today it is marketed to enhance memory and to treat a variety of circulatory ailments.[29] *Ginkgo biloba* extract does not appear to enhance cognitive function in healthy adults, and evidence that it can reduce the incidence of dementia or protect against cognitive decline in the elderly is inconsistent.[30–32] Taking *Ginkgo biloba* may cause side effects that include headaches and gastrointestinal symptoms (Table F4.3).[33] *Ginkgo biloba* also interacts with a number of medications. It can cause bleeding when combined with warfarin or aspirin, elevated blood pressure when combined with a thiazide diuretic, and coma when combined with the antidepressant trazodone.[34]

St. John's Wort

St. John's wort is taken to promote mental well-being (Figure F4.6B). Analysis reveals that it contains low doses of the chemical found in the antidepressant drug fluoxetine (Prozac). The results of clinical trials suggest that it is effective for the treatment of depression.[35] Side effects include nausea and sensitivity to sunlight. St. John's wort should not be used in conjunction with prescription antidepressant drugs, and it has been found to interact with anticoagulants, heart medications, birth control pills, immunosuppressants, antibiotics, medications used to treat HIV infection, and others.[33,34]

Ginseng

Ginseng has a long history in traditional medicine (Figure F4.6C). It has been used in Asia for centuries for its energizing, stress-reducing, and aphrodisiac properties. Today it is popular because it is suggested to improve mental and physical performance, augment immune function, and enhance sexual function. Although ginseng contains substances that have antioxidant, anti-inflammatory, and immunostimulating effects, there is little evidence that it has any health benefits.[36] Despite its history of use in Chinese medicine, ginseng may not be safe for everyone. It can alter bleeding time, and therefore should not be used by those taking warfarin, and it has been found to interact with other medications such as estrogens, corticosteroids, antidepressants, and morphine. Even in those not taking other medications, it may cause side effects such as diarrhea, headache, and insomnia.

Garlic

Throughout history garlic has been used for a lot more than to keep vampires away (Figure F4.6D). Hippocrates, who is considered the father of Western

TABLE F4.3 Potential Benefits and Side Effects of Common Herbal Ingredients

Product	Suggested benefit and uses	Side effects
Astragalus (bei qi, huang qi, ogi, hwang ki, milk vetch)	Enhances the immune system.	Can interact with drugs that suppress the immune system and affect blood sugar levels and blood pressure.
Bitter orange (Seville orange, sour orange, Zhi shi)	Relieves heartburn and nasal congestion, stimulates appetite, promotes weight loss.	Increased heart rate and blood pressure, fainting, heart attack, stroke.
Cat's claw (uña de gato)	Relieves arthritis and stimulates the immune system.	Headache, dizziness, vomiting; should not be taken by individuals who are pregnant.
Chamomile	Relieves gastrointestinal upset, promotes relaxation and sleep.	Allergic reactions.
Dandelion (lion's tooth, blowball)	Relieves minor digestive problems, increases urine production, supports liver and kidney health.	Upset stomach and diarrhea, allergic reactions.
Echinacea (purple coneflower, coneflower)	Stimulates the immune system, prevents and treats colds and other upper respiratory infections.	Allergic reactions.
Ephedra (ma huang, Chinese ephedra)	Treats colds and nasal congestion, aids in weight loss, increases energy, and enhances athletic performance.	High blood pressure, irregular heartbeat, heart attack, stroke, death; banned by the FDA, but the ban does not apply to traditional Chinese herbal remedies or to products like herbal teas regulated as conventional foods.
Ginger	Relieves motion sickness and nausea.	Gas, bloating, heartburn, nausea.
Ginkgo (*Ginkgo biloba*, maiden-hair tree, fossil tree)	Improves memory and mental function, improves circulation.	Gastrointestinal distress, headache, dizziness, allergic skin reactions.
Ginseng (Asian ginseng, Chinese ginseng)	Increases sense of well-being and stamina, improves mental and physical performance, enhances immune function, improves sexual function, lowers blood glucose, controls blood pressure.	Headache, insomnia, gastrointestinal upset with prolonged use; interferes with the action of the blood thinner warfarin.
Hawthorn	Strengthens heart muscle.	Possible drug interactions.
Hoodia (Kalahari cactus, xhoba)	Suppresses appetite.	Safety unknown; potential risks, side effects, and interactions with medicines and other supplements have not been studied.
Kava (kava kava, awa, kava peeper)	Relieves anxiety, stress, insomnia, menopausal symptoms.	Liver damage, including hepatitis and liver failure (which can cause death); FDA has issued a warning that using kava supplements has been linked to severe liver damage.
Milk thistle (Mary thistle, holy thistle)	Protects against liver disease; improves liver function.	Gastrointestinal upset, allergic reactions, low blood sugar.
Red clover (cow clover, meadow clover, wild clover)	Relieves menopausal symptoms, breast pain associated with menstrual cycles, and symptoms of prostate enlargement; lowers blood cholesterol.	Headache, nausea, rash.
Saw palmetto (American dwarf palm tree, cabbage palm)	Improves urinary flow with enlarged prostate.	Mild stomach discomfort, headache, fatigue, decreased libido, rhinitis.
St. John's wort (hypericum, Klamath weed, goatweed)	Promotes mental well-being; treats depression, anxiety, and/or sleep disorders.	Increased sensitivity to sunlight, anxiety, dry mouth, dizziness, gastrointestinal symptoms, fatigue, headache, sexual dysfunction; interacts with many medications, including antidepressants, birth control pills, digoxin, warfarin, and seizure-control drugs.
Valerian (all-heal, garden heliotrope)	Acts as a mild sedative, relieves sleep disorders and anxiety.	Gastrointestinal upset, headache, and tiredness possible with prolonged use.
Yohimbe (yohimbe bark)	Acts as an aphrodisiac; treats sexual dysfunction, including erectile dysfunction in men.	High blood pressure, increased heart rate, headache, anxiety, dizziness, nausea, vomiting, tremors, and sleeplessness.

Sources: National Center for Complementary and Alternative Medicine, *Herbs at a Glance,* Office of Dietary Supplements, *Dietary Supplement Fact Sheets,* and Office of Dietary Supplements, *Botanical Supplement Fact Sheets.*

medicine, recommended garlic to treat pneumonia and other infections, as well as cancer and digestive disorders. Although it is no longer recommended for these purposes, recent research has shown that it may cause a modest reduction in blood cholesterol and triglyceride levels.[37] Eating enough garlic to lower cholesterol will probably keep your friends and family away, as well as the vampires, so supplement manufacturers have provided a way to increase intake without eating this odiferous food at every meal; some preparations contain a deodorized form. Even though we spice our food with it, garlic supplements are not safe for everyone. The National Institutes of Health has concluded that these supplements interfere with drugs used to treat HIV infection and can increase the risk of bleeding, so they should be used with caution before having surgery or dental work.[38]

Echinacea

Native Americans used petals of the echinacea plant as a treatment for colds, flu, and infections (**Figure F4.6E**). Today, the echinacea root is popular as an herbal cold remedy. Echinacea is believed to act as an immune system stimulant; studies are mixed as to whether it is beneficial in either preventing or treating the common cold.[39] Although side effects have not been reported, allergies are possible.

Saw Palmetto

Traditionally, saw palmetto, which comes from the berries of the American dwarf palm (**Figure F4.6F**), has been used to treat problems of the urinary and genital tract; enhance sperm production, breast size, or libido; and as a mild diuretic. Today, it is marketed to treat prostate enlargement and therefore improve urinary flow. A review of the effectiveness of this supplement found that it provides mild to moderate improvement in urinary symptoms and flow measures. No drug interactions have been reported. Available data suggest that saw palmetto is well tolerated by most users. Most side effects, including abdominal pain, decreased libido, headache, fatigue, nausea, and rhinitis, are mild.[40]

Kava

Kava is traditionally served as a special drink at ceremonies such as weddings and coming-out-of-mourning celebrations in the South Pacific. It is used today to relieve stress and anxiety. A review of the effectiveness of kava concluded that administration is effective in reducing anxiety.[41] However, kava may not be the safest way to relieve stress. In 2002 the FDA issued a warning about kava because it may cause liver damage, including hepatitis, cirrhosis, and liver failure. It has been taken off the market in many European countries and in Canada, Australia, and Singapore because of this danger.

CHAPTER OUTLINE

13.1 Nutrition, Physical Activity, and Health
- How Physical Activity Improves Fitness
- How Physical Activity Benefits Health

13.2 Physical Activity Recommendations
- What to Look For in a Fitness Program
- Physical Activity Recommendations for Children
- How to Create an Active Lifestyle

13.3 Exercise and Energy Metabolism
- How Exercise Duration Affects Metabolism
- How Exercise Intensity Affects Metabolism
- Why Training Increases Aerobic Capacity

13.4 Energy and Nutrient Needs for Physical Activity
- Energy Needs
- Carbohydrate, Fat, and Protein Needs
- Vitamin and Mineral Needs

13.5 Fluid Needs for Physical Activity
- How Dehydration Affects Health and Performance
- Why Heat-Related Illness Is a Concern for Athletes
- Causes and Consequences of Hyponatremia
- Recommended Fluid Intake for Exercise

13.6 Food and Drink to Maximize Performance
- Maximizing Glycogen Stores
- What to Eat Before Exercise
- What to Eat During Exercise
- What to Eat After Exercise

13.7 Ergogenic Aids: Do Supplements Enhance Athletic Performance?
- Vitamin and Mineral Supplements
- Supplements to Build Muscle
- Supplements to Enhance Performance in Short, Intense Activities
- Supplements to Enhance Endurance
- How Diet and Supplements Affect Performance

(©iStockphoto)

© mbbirdy/iStockphoto

Nutrition and Physical Activity

13

CASE STUDY

© technotr/iStockphoto

Jason bought a road bike a year ago. He lives in a rural area where he can ride away from the traffic and enjoy the countryside. He typically goes for a 15- or 20-mile ride a few evenings after work, and on the weekends he often rides as far as 30 miles. A friend suggested they sign up for a weeklong ride in Oregon in the fall. The route would require riding 60 to 80 miles a day, often over mountain passes in the Cascades. Jason is thrilled by the challenge. He trains over the summer by finding hillier routes and increasing his distances. By the start of the Oregon ride, he is fit and ready. During the ride, water, sports drinks, and snacks or lunch are provided every 20 miles. Jason and his friend do great the first day. They stop and eat and fill their water bottles at all the rest stops and complete the 75-mile ride by 3:30 in the afternoon. The next day the route takes them to Crater Lake. Jason is feeling great and is excited about visiting this extinct volcano, so he convinces his friend to ride past the second rest stop and hurry up to the lake. His friend is carrying an extra water bottle and has some snack bars in his pocket, which he eats soon after the skipped rest stop. Jason is less prepared. He feels fine for about 10 miles and then the road to Crater Lake turns steeply uphill for about 12 miles. Jason's water bottle is now empty and so is his stomach. His legs feel weak and he has no energy. How could he have felt so great yesterday and so awful today? With his friend's encouragement, he struggles slowly on to the lunch stop at the rim of the crater. **Why was he so fatigued?**

13.1 Nutrition, Physical Activity, and Health

LEARNING OBJECTIVES

- Discuss how nutrition and physical activity interact to promote health.
- Describe the characteristics of a fit individual.
- Explain what is meant by the *overload principle*.
- Evaluate the impact of physical activity on health.
- Discuss the role of physical activity in weight management.

fitness The ability to perform routine physical activity without undue fatigue.

overload principle The concept that the body will adapt to the stresses placed on it.

cardiorespiratory endurance The efficiency with which the body delivers to cells the oxygen and nutrients needed for muscular activity and transports waste products from cells.

aerobic exercise Endurance exercise such as jogging, swimming, or cycling that increases heart rate and requires oxygen in metabolism.

Healthy food choices and physical activity are both necessary to achieve optimal health. The right foods provide the nutrients needed to promote health and reduce disease risk. Adequate physical activity improves **fitness** and overall health. However, the link between good nutrition and physical activity goes beyond the fact that both promote health and reduce disease risk. Physical activity burns calories and utilizes nutrients, which must be supplied by the diet. Therefore, the foods you eat are necessary to fuel activity and optimize athletic performance (Figure 13.1). The connection between diet and physical activity holds true whether your fitness goal is to keep your weight in the healthy range, to reduce your risk of chronic disease, to be able to complete your daily activities, or to perform optimally in athletic competitions.

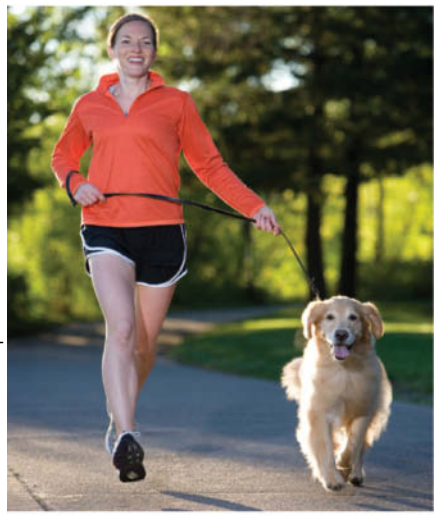
How Physical Activity Improves Fitness

Being fit is an important part of being healthy. Fitness level is defined by endurance, strength, flexibility, and body composition. Engaging in regular exercise improves these parameters. When you exercise, changes occur in your body: You breathe harder, your heart beats faster, and your muscles stretch and strain. If you exercise regularly, your body adapts to the exercise you perform and as a result can continue for a few minutes longer, lift a heavier weight, or stretch a millimeter farther. This is known as the **overload principle**: The more you do, the more you are capable of doing. For example, if you run a given distance three times a week, in a few weeks you can run farther; if you lift weights a few days a week, in a few weeks you will have more muscle and will be able to lift more weight more easily. These adaptations improve overall fitness.

Cardiorespiratory Endurance How long you can jog or ride your bike depends on the ability of your cardiovascular and respiratory systems, referred to jointly as the cardiorespiratory system, to deliver oxygen and nutrients to your tissues and remove wastes. **Cardiorespiratory endurance** is increased by **aerobic exercise**, the type of exercise that increases heart rate and

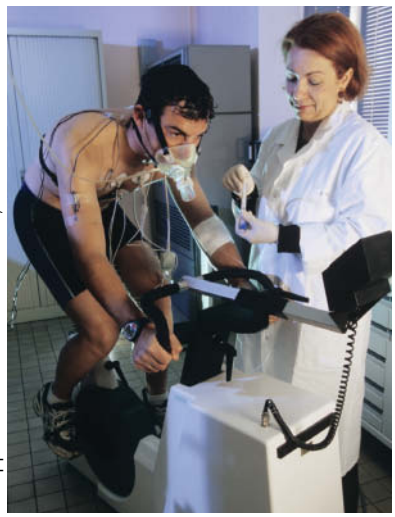
FIGURE 13.1 Nutrition and physical activity affect health
The energy and nutrients in food fuel our activity, and physical activity in turn affects our energy and nutrient needs. Both good nutrition and physical activity are necessary for optimal health.

FIGURE 13.2 Cardiorespiratory endurance and aerobic capacity



© Joe Michl/iStockphoto/

A. The cardiovascular and respiratory systems are strengthened by aerobic exercise, such as jogging, bicycling, and swimming. A guideline to assess whether an activity is aerobic is that the intensity is low enough for you to carry on a conversation while exercising but high enough that you cannot sing.



Philippe Psaila/Photo Researchers, Inc.

B. To measure this athlete's aerobic capacity he rides a stationary bicycle while his oxygen consumption (oxygen inhaled – oxygen exhaled) is measured. His exercise workload is increased gradually by increasing resistance on the bike until he can no longer continue. The amount of oxygen consumed at the highest workload achieved is his aerobic capacity.

stroke volume The volume of blood pumped by each beat of the heart.

resting heart rate The number of times that the heart beats per minute while a person is at rest.

aerobic capacity or **VO_2 max** The maximum amount of oxygen that can be consumed by the tissues during exercise. This is also called maximal oxygen consumption.

uses oxygen. Aerobic activities include walking, dancing, jogging, cross-country skiing, cycling, and swimming (Figure 13.2A).

Regular aerobic exercise increases cardiorespiratory endurance because it strengthens the heart muscle and increases **stroke volume**, which is the amount of blood pumped with each beat of the heart. This in turn decreases **resting heart rate**, the rate at which the heart must beat to supply blood to the tissues at rest. The more fit a person is, the lower their resting heart rate and the more blood their heart can pump to muscles during exercise. In addition to increasing the amount of oxygen-rich blood that is pumped to muscles, regular aerobic exercise increases the muscle's ability to use oxygen to produce ATP. The body's maximum ability to generate ATP by aerobic metabolism during exercise is called **aerobic capacity**, or **VO_2 max**.

Aerobic capacity is dependent on the ability of the cardiorespiratory system to deliver oxygen to the cells and the ability of the cells to use oxygen to produce ATP. The greater a person's aerobic capacity, the more intense activity he or she can perform before a lack of oxygen affects performance. A trained athlete will have a greater aerobic capacity than an untrained individual. Aerobic capacity can be determined in an exercise laboratory by measuring oxygen consumption or uptake during maximal exercise on a stationary bicycle or treadmill (Figure 13.2B).

Muscle Strength and Endurance Greater muscle strength enhances the ability to perform tasks such as pushing or lifting. In daily life, this could mean lifting a gallon of milk off the top shelf of the refrigerator with one hand, carrying a full trash can out to the curb, or moving a couch into your new apartment. Greater muscle endurance enhances your ability to continue repetitive muscle activity, such as shoveling snow or raking leaves. Muscle strength and endurance are increased by repeatedly using muscles in activities that require moving against a resisting force. This type of exercise is called **muscle-strengthening exercise**, strength training, or resistance exercise, and includes activities such as weightlifting and calisthenics (Figure 13.3). Lifting a heavy weight stresses muscles. This stress or overload causes muscles to adapt by increasing in size and strength—a process called **hypertrophy**. The larger, stronger muscles can now lift the same weight more easily.

muscle-strengthening exercise Activities that are specifically designed to increase muscle strength, endurance, and size; also called strength training or resistance exercise.

hypertrophy An increase in the size of a muscle or organ.

Wang Leng/Asia Images/Getty Images, Inc.

FIGURE 13.3 Increasing muscle size and strength
Building muscle requires an increase in the amount of resistance exercise. Progressively increasing the amount of weight at each exercise session slowly causes the muscle to hypertrophy.

atrophy Wasting or decrease in the size of a muscle or other tissue caused by lack of use.

When muscles are not used due to a lapse in training, an injury, or illness, they become smaller and weaker. This process is called **atrophy**. For example, when individuals are bedridden and unable to move about, their muscles atrophy. Once they are up and active again, their muscles regain strength and size. There is truth in the expression "Use it or lose it."

Flexibility Fitness is not just about bulging muscles; it also involves flexibility. Flexibility determines range of motion—how far you can bend and stretch muscles and ligaments. Regularly moving the limbs, neck, and torso through their full ranges of motion helps increase and maintain flexibility. Poor flexibility makes it difficult to bend to tie your shoes or stretch to remove packages from the car. Being flexible can enhance postural stability and balance.[1] Stretching improves flexibility and in some situations, can reduce the risk of injury.[2] As seen in Figure 13.4, stretching exercises can be static or dynamic. Static stretching involves holding a stretch in a challenging but comfortable position for a period of time. Dynamic stretching uses muscle contractions and momentum to repeatedly move through a challenging but comfortable range of motion. What combination is best depends on the person and his or her sport.[3]

How Exercise Affects Body Composition Exercise builds and maintains muscle. Individuals who are physically fit have a greater proportion of lean body tissue than unfit individuals of the same body weight (Figure 13.5). Not everyone who is fit is thin, but in a fit person who carries extra pounds, more of the weight is from muscle. How much body fat a person has is also affected by gender and age. In general, women have more stored body fat than men. For young adult women, the desirable percentage of body fat is 21 to 32% of total weight; in adult men, the desirable percentage is about 8 to 19%.[4] With aging, lean body mass decreases in both men and women, and the percentage of body fat increases even if body weight remains the same. Some of this change may be prevented by staying physically active (see Chapter 16).

FIGURE 13.4 Types of stretching

A. To most of us, stretching means static stretching. In a static stretch you get into a position that stretches a muscle or group of muscles to its farthest point and then hold that position.

RW Photographic/Masterfile

Thomas Barwick/Getty Images

B. Most athletes incorporate dynamic stretching into their warm-up. This uses controlled torso twists, side lunges, or leg and arm swings to extend muscles gently to the limits of their range of motion.

How Physical Activity Benefits Health

In addition to making the tasks of everyday life easier, maintaining fitness through regular activity offers many health benefits. Regular exercise can help to prevent or delay the onset of cardiovascular disease, hypertension, stroke, diabetes, and colon and breast cancer (Figure 13.6).[1,5] Physical activity also helps maintain muscles, bones, and joints, and reduces the risk of osteoporosis. It makes it easier to maintain a healthy body weight and can prevent depression and improve mood, sleep patterns, and overall outlook on life.

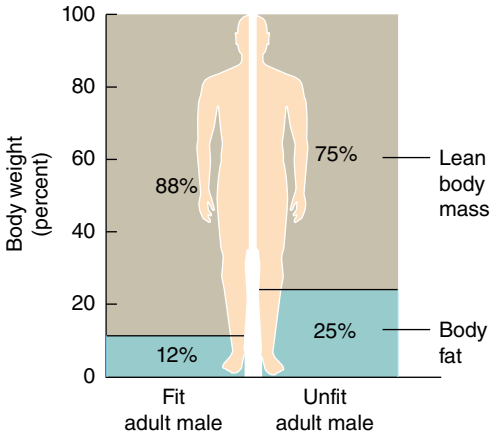


FIGURE 13.5 Body composition
Body composition, which refers to the percentage of fat versus nonfat or lean tissue (muscle, bones, cartilage, skin, nerves, and internal organs), is an indicator of health and fitness. Engaging in aerobic exercise and muscle-strengthening exercise has a positive impact on body composition, reducing body fat and increasing the proportion of lean tissue.

Cardiovascular Health Regular exercise reduces the risk of cardiovascular disease.[1] Because aerobic exercise strengthens the heart muscle, it reduces the number of times the heart must beat to deliver blood to the tissues at rest and during exercise. The changes that occur with exercise also help to lower blood pressure and increase HDL cholesterol levels in the blood.[6] All these effects help to reduce the risk of cardiovascular events such as heart attack and stroke.

Diabetes Prevention and Management People with excess body fat are more likely to develop diabetes. By keeping body fat within the normal range, exercise can decrease the risk of developing type 2 diabetes. Physical activity that includes both aerobic exercise and strength training is also important in the treatment of diabetes because exercise increases the sensitivity of tissues to insulin. Therefore, people with diabetes need to coordinate exercise, diet, and medication to avoid hypoglycemia. In type 2 diabetes, maintaining an exercise program can reduce the need for medication to maintain normal blood glucose levels.

VIDEO

Cancer Risk Epidemiological evidence suggests that individuals who exercise regularly may be reducing their cancer risk by 20 to 30%.[7] Physical activity is hypothesized to reduce the risk of cancer by helping to maintain a healthy body weight, regulating hormone levels, reducing inflammation, and improving immune system function.[7,8] The strongest evidence that exercise

Courtesy Lori Smolin

Exercise increases the sensitivity of tissues to insulin and regular exercise decreases the risk of developing type 2 diabetes.

Regular exercise improves flexibility and balance.

The strength and flexibility promoted by exercise can help improve joint function.

Regular exercise reduces the risk of cardiovascular disease because it strengthens the heart muscle, lowers blood pressure, and increases HDL (good) cholesterol levels in the blood.

Regular exercise reduces the risk of colon cancer and breast cancer.

Regular exercise increases muscle mass, strength, and endurance.

Weight-bearing exercise stimulates bones to become denser and stronger and therefore reduces the risk of osteoporosis.

FIGURE 13.6 Health benefits of physical activity
Maintaining fitness through regular exercise helps you live longer by promoting a healthy weight and reducing the risk of chronic disease, and it helps you feel better by improving sleep patterns and self-image and relieving stress, anxiety, and depression.

reduces cancer risk is for colon and breast cancer. Adults who increase the intensity, frequency, or duration of physical activity may reduce their risk of developing colon cancer by 30 to 40% relative to those who are sedentary, with the greatest risk reduction seen among those who are most active.[8] Higher physical activity also is associated with better survival in those with colorectal cancer.[9] Epidemiology also supports a relationship between physical activity and a lower risk of breast cancer, but the degree of risk reduction varies widely.[8] There is more limited evidence that physical activity reduces the risk of other cancers such as lung, prostate, ovary, gastric, and pancreatic cancer.[7] When evaluating the impact of exercise on cancer risk, diet and other lifestyle factors also must be considered. It is possible that some of the effect is due to the fact that people who exercise regularly are more likely to have healthier overall diets and lifestyles.

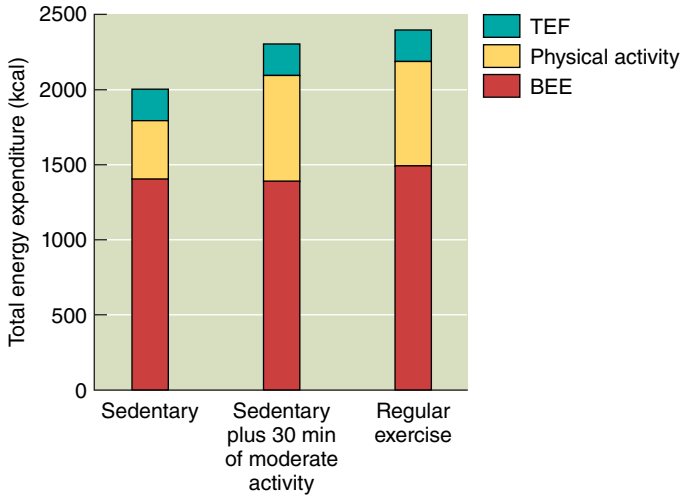
Bone and Joint Health Just as lifting weights helps maintain muscle size and strength, weight-bearing exercise stimulates bones to become denser and stronger. One of the causes of bone loss, like muscle loss, is lack of use; therefore, weight-bearing exercise such as walking, running, and aerobic dance can increase peak bone mass and prevent bone loss, reducing the risk of osteoporosis (see Chapter 11). An exercise program can also benefit individuals with arthritis because the strength and flexibility promoted by exercise help manage pain and allow arthritic joints to move more easily.[10]

Weight Management People who exercise regularly are more likely to maintain a healthy body weight. Physical activity makes weight management easier because it increases energy needs so more calories can be consumed without weight gain. During exercise, energy expenditure can rise well above the resting rate and some of this increase persists for many hours after activity slows.[11] Physical activity can also boost energy expenditure through its effect on body composition. Exercise increases lean tissue mass and because, even at rest, lean tissue uses more energy than fat tissue, this increases basal energy needs. The combination of increased energy output during exercise, the rise in expenditure that persists after exercise, and the increase in basal needs can have a major impact on total energy expenditure (Figure 13.7). Besides increasing energy needs, exercise also promotes the loss of body fat and slows the loss of lean tissue that occurs with energy restriction. This makes exercise an essential component of any weight-reduction program.

Overall Well-Being Regular exercise improves the quality of life by having a positive effect not only on physical health, but also on mental health. It improves mood and promotes a positive self-esteem and better cognition, while decreasing the chances of depression, anxiety, and burnout.[12,13] The exact mechanisms involved are not clear, but one hypothesis has to do with the production of **endorphins**. Exercise stimulates the release of these chemicals, which are thought to be natural mood enhancers that play a role in triggering what athletes describe

endorphins Compounds that cause a natural euphoria and reduce the perception of pain under certain stressful conditions.

FIGURE 13.7 Physical activity and total energy expenditure
Total energy expenditure is the sum of the energy used for basal energy expenditure (BEE), physical activity, and the thermic effect of food (TEF). Adding 30 minutes of moderate activity can increase total energy expenditure by as much as 300 kcal. Regular exercise increases muscle mass, which increases BEE, further increasing total energy expenditure.



THINK CRITICALLY

Why does regular exercise cause an increase in basal energy expenditure?

as an "exercise high." In addition to causing this state of exercise euphoria, endorphins are thought to aid in relaxation, pain tolerance, and appetite control. Regular exercise is also associated with a lower risk of cognitive decline and dementia.[1] It may benefit mental well-being by affecting the levels of certain mood-enhancing neurotransmitters in the brain, releasing muscle tension, improving sleep patterns, and reducing levels of the stress hormone cortisol. Exercise also raises body temperature, which is believed to have a calming effect. These changes in both the brain and the body can reduce anxiety, irritability, stress, fatigue, anger, self-doubt, and hopelessness.[12]

13.2 Physical Activity Recommendations

LEARNING OBJECTIVES

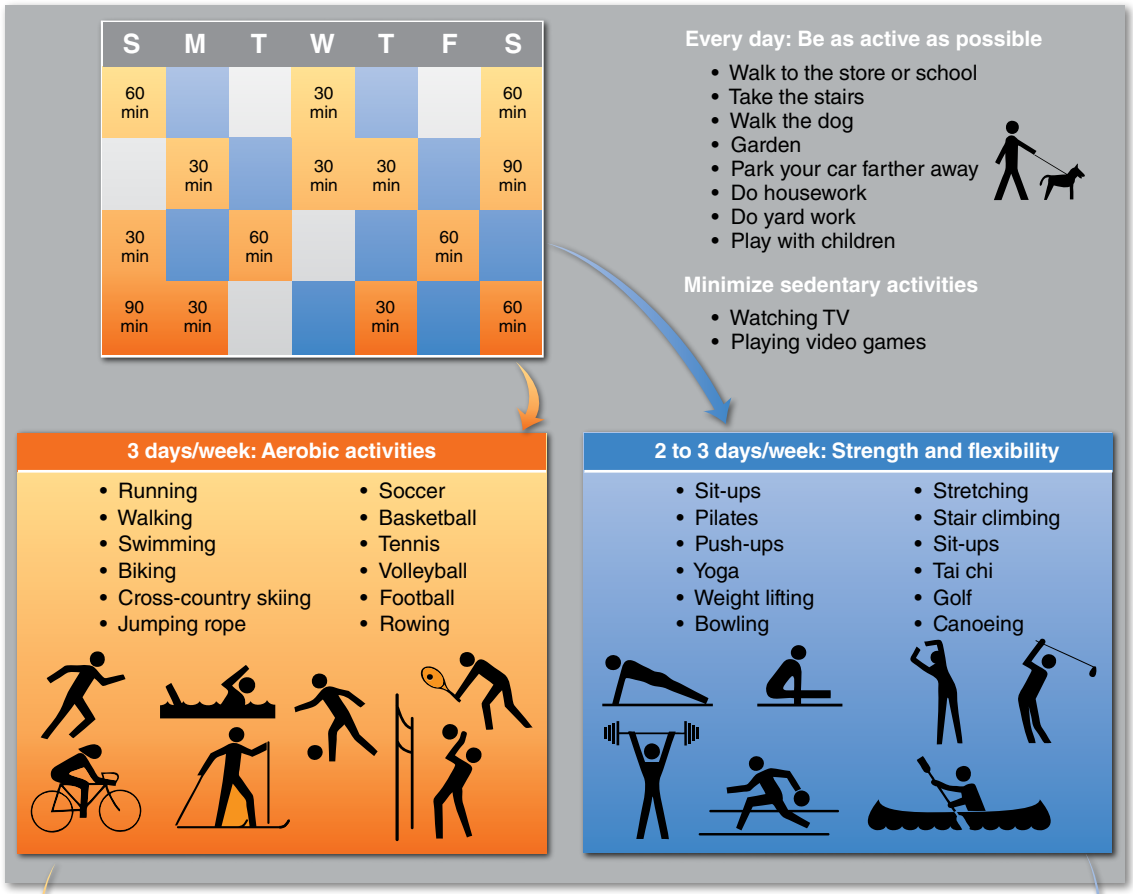
- Describe the amounts and types of physical activity recommended to improve health.
- Classify activities as aerobic or anaerobic.
- Plan a fitness program that can be integrated into your daily routine.
- Explain overtraining syndrome.

To reduce the risk of chronic disease, public health guidelines, including the Dietary Guidelines, advise a minimum of 150 minutes of moderate-intensity (~30 min/day, five days a week) or 75 minutes of vigorous-intensity aerobic physical activity each week (or an equivalent combination of both).[1,5,14] Additional health benefits can be obtained by increasing aerobic physical activity to 300 minutes of moderate-intensity (~60 min/day, five days a week) or 150 minutes of vigorous-intensity aerobic physical activity each week (or an equivalent combination of both).[5,11] Additional health benefits are gained by exercising beyond this amount. As a rule of thumb, an activity with an intensity rating of 5 to 6 on a scale of 1 to 10, with 1 being lying on the couch and 10 being maximal activity, is considered moderate. For most people, moderate-intensity exercise is the equivalent of walking three miles in about an hour or bicycling eight miles in about an hour. Vigorous-intensity exercise is equivalent to jogging at a rate of five miles per hour or faster or bicycling at 10 miles per hour or faster.[5] Adults should also include muscle-strengthening activities on two or more days per week, but time spent in muscle-strengthening activities does not count toward meeting the aerobic activity guidelines. Only about 20% of adults in the United States meet the physical activity guidelines for both aerobic and muscle-strengthening activity, and fewer than 3 in 10 high school students get 60 minutes of activity per day.[15,16]

In addition to following these physical activity recommendations, it is important to minimize sedentary time. A few hours of planned exercise cannot compensate for extended periods of time spent in sedentary pastimes. Therefore, even people who meet exercise guidelines may be at increased risk of cardiovascular disease, depression, increased waist circumference, and other adverse effects if they spend long periods sitting in a car, at a desk, or in front of the television.[1,17] Reducing total time spent in sedentary pursuits and breaking up periods of sedentary activity with short bouts of physical activity and standing, which can attenuate the adverse effects of sedentary behavior, should be a goal for all adults, irrespective of their exercise habits.

What to Look for in a Fitness Program

A well-planned fitness regimen includes aerobic exercise, which raises heart rate and therefore improves cardiorespiratory fitness; resistance exercises, which increase muscle strength and endurance and maintain or increase muscle mass; stretching, which promotes and maintains flexibility; and exercises that focus on balance, agility, and coordination, referred to as neuromotor exercise.[1,5] Exercise should be integrated into an active lifestyle that includes a variety of everyday activities, enjoyable recreational activities, and a minimum amount of time spent in sedentary activities (Figure 13.8).



	Recommendation	
	Intensity	***Frequency/Duration***
Aerobic	Moderate: Raise heart rate to 60 to 69% of maximum or Vigorous: Raise heart rate to 70 to 85% of maximum	5 to 7 days/week for 30 to 60 minutes or 3 to 7 days/week for 25 to 60 minutes
Muscle strengthening	Use resistance that is heavy enough for muscles to be near exhaustion after 8 to 12 repetitions	2 to 3 nonconsecutive days/week, 8 to 10 exercises for all major muscle groups, repeat each lift 8 to 12 times
Flexibility	Extend to position of mild discomfort	2 to 7 days/week, hold each stretch for 10 to 30 seconds, and repeat each stretch 3 to 5 times

FIGURE 13.8 A summary of physical activity recommendations
A healthy lifestyle minimizes sedentary activities and includes a variety of everyday activities as well as aerobic exercise and exercises that improve muscle strength, flexibility, and balance. Achieving the recommended amounts of these activities will help improve and maintain fitness and health. In general, more exercise is better than less.

maximum heart rate The maximum number of beats per minute that the heart can attain. It declines with age.

How Much Aerobic Activity? Aerobic activities, such as walking, bicycling, skating, swimming, or jogging, should be performed for at least 30 to 60 minutes per day, depending on intensity, most days of the week. An activity is in the aerobic zone if it raises heart rate to 60 to 85% of its maximum (Figure 13.9). **Maximum heart rate** is the maximum number of beats per minute that the heart can attain. It is dependent on age and can be estimated in men by subtracting age from 220 and in women by subtracting 88% of age from 206.[18] Each exercise session should begin with a warm-up, such as mild stretching and easy jogging, to increase blood flow to the muscles, and end with a cooldown period, such as walking or stretching, to help prevent muscle cramps and slowly reduce heart rate.

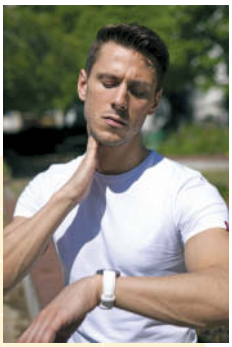
FIGURE 13.9 The aerobic zone

A. You can calculate your aerobic zone by multiplying your maximum heart rate by 0.6 and 0.85. Maximum heart rate depends on age; it can be estimated for men and women by using the following equations:

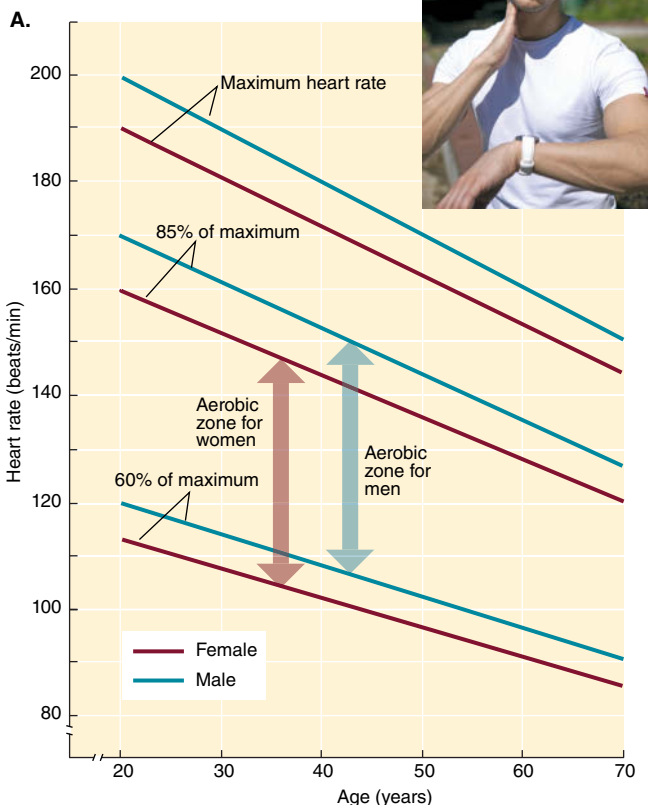
Men: maximum heart rate = 220 − age
Women: maximum heart rate = 206 − (0.88 × age)

For example, a 20-year-old male would have a maximum heart rate of 200 (220 − 20) beats per minute. If he exercises at a pace that keeps his heart rate between 120 (0.6 × 200) and 170 (0.85 × 200) beats per minute, he is in his aerobic zone.

B. You can check your heart rate by feeling the pulse at the side of your neck, just below the jawbone. A pulse is caused by the heart beating and forcing blood through the arteries. The number of pulses per minute equals heart rate.



Michael Newman/PhotoEdit



THINK CRITICALLY

What is the aerobic zone for a 30-year-old woman? What happens to this range when she turns 40? Why do you think this change occurs?

Aerobic activities of different intensities can be combined to meet recommendations and achieve health benefits. The total amount of energy expended in physical activity depends on the intensity, duration, and frequency of the activity. Vigorous physical activity, such as jogging, that raises heart rate to the high end of the aerobic zone (70 to 85%) improves fitness more and burns more calories per unit of time than does moderate-intensity activity, such as walking, that raises heart rate only to the low end of the aerobic zone (60 to 69%). For a sedentary individual beginning an exercise program, even mild exercise such as walking can raise the heart rate into the aerobic zone. As fitness improves, exercisers must perform more intense activity to raise their heart rates to this level.

How Much Muscle-Strengthening Exercise? Muscle-strengthening exercises, such as weightlifting, should be done two to three days a week at the start of a fitness program, and two days a week after the desired strength has been achieved. Adults should wait at least 48 hours between each muscle-strengthening session. Each session should include a minimum of 8 to 10 exercises that train the major muscle groups. One to three sets of 8 to 12 repetitions of each exercise is recommended. The resistance should be great enough to cause the muscle to be near exhaustion after the 8 to 12 repetitions. Increasing the resistance will increase muscle strength, whereas increasing the number of repetitions will improve endurance.

For older adults, neuromotor exercise should be included in an exercise program.[1] This type of exercise helps improve balance, agility, and muscle strength and reduce the risk of falls. Good options include tai chi and yoga, which use combinations of neuromotor exercise, resistance exercise, and flexibility exercise.

Stretching A combination of static and dynamic stretching can be used to improve range of motion. To improve and maintain flexibility, stretching exercises that target the major muscles and tendons of the shoulders, chest, neck, trunk, lower back, hips, legs, and ankles should be done at least two to three days a week.[1] Muscles should be stretched to a position of mild discomfort and held for 10 to 30 seconds. Each stretch should be repeated three to five times to achieve a total stretching time of 60 seconds. Although flexibility is an important component of fitness, time spent stretching should not be counted toward the goal of at least 150 minutes of aerobic activity per week.[5]

Physical Activity Recommendations for Children

Children and adolescents should spend at least 60 minutes per day in developmentally appropriate physical activity.[5,14] Aerobic, muscle-strengthening, and bone-strengthening activities should be included in this 60 minutes. Most of the 60 minutes should be from moderate- and vigorous-intensity aerobic activity, with vigorous-intensity activity at least three days per week. Muscle-strengthening and bone-strengthening activities should also be included at least three days per week. Muscle-strengthening exercise can be unstructured play activities such as climbing on playground equipment or playing tug of war. Bone-strengthening activities include weight-bearing play such as hopscotch, jumping rope, basketball, and running. Activity for young children should be intermittent, with periods of moderate to vigorous activity lasting 10 to 15 minutes or more along with periods of rest and recovery. To promote the recommended amount of exercise, a variety of enjoyable activities should be stressed and competition de-emphasized.

Modern lifestyles do not promote activity in children and adolescents; television, computers, video games, and cell phone activities are often chosen over physical activity. Reducing the amount of time spent in these sedentary activities can increase fitness, lower BMI, and improve blood pressure and cholesterol levels. Children who learn to enjoy physical activity are more likely to be active adults who maintain a healthy body weight and have a lower risk of cardiovascular disease, diabetes, osteoporosis, and certain types of cancer. Learning by example is always best. Children who have physically active parents are the leanest and the fittest (Figure 13.10).

How to Create an Active Lifestyle

Almost everyone can participate in some form of activity, no matter where they live, how old they are, or what physical limitations they have. Exercise classes are taught in nursing homes. People with heart disease, visual impairments, and physical disabilities compete in athletic events. You are never too old to exercise, and it is never too late to start.

Find Convenient, Enjoyable Activities Incorporating exercise into day-to-day life may require a behavior change, and changing behavior is not easy. The first step in beginning an exercise program is to recognize the reasons for not being active and identify ways to overcome them. Many people avoid exercise because they do not enjoy it, feel they have to join an expensive health club, have little motivation to do it alone, or find it inconvenient and uncomfortable. Finding a type of activity that is enjoyable, a time that is realistic and convenient, and a place that is appropriate and safe are important first steps in adopting an exercise program. Riding your bike to class or work rather than driving or taking the bus, taking a walk during your lunch break, and enjoying a game of catch or tag with your children are all effective ways to increase your everyday activity level. The goal is to make gradual lifestyle changes that increase physical activity. Behavioral strategies such as those listed in Table 13.1 may help promote regular exercise.

Asia Images Group/Getty Images, Inc.

FIGURE 13.10 Physical activity for children
Creating active environments for children at home, in schools, and in communities can help children participate in and enjoy exercise. Community parks, bike paths, and hiking trails promote active lifestyles for adults, children, and families.

Keep Exercise Safe Safety should be a consideration in planning any fitness regimen. Before beginning, everyone should check with their physician to be sure that their plans are safe considering their medical history. Then the location and environment for exercise can be considered. Busy work schedules often force people to exercise in the dark, early morning or evening hours. Exercisers who use the street for walking or jogging should wear light-colored, reflective clothing so they can be seen by motorists. Exercising with a partner is safer and more enjoyable.

Weather conditions can also be a safety concern. Physical activity produces heat, which normally is dissipated to the environment, partly by the evaporation of sweat. When the environmental temperature is high, heat is not efficiently transferred to the environment, and when humidity is high, sweat evaporates slowly, making it difficult to cool the body. Thus, exercise should be reduced or curtailed in hot and humid conditions. Cold environments can also pose problems for the outdoor exerciser. In general, cold does not impair exercise capacity, but the numbing of exposed flesh and the bulk of extra clothing can cause problems for joggers and bicyclists. Clothing should allow

TABLE 13.1 Suggestions for Starting and Maintaining an Exercise Program

Start slowly. Set specific attainable goals. Once you have met them, add more.
• Walk around the block after dinner.
• Get off the bus or subway one stop early.
• Use half of your lunch break to exercise.
• Do a few biceps curls each time you take the milk out of the refrigerator.
Make your exercise fun and convenient.
• Opt for activities you enjoy—bowling and dancing are more fun than a treadmill in the basement.
• Find a partner to exercise with you.
• Choose times that fit your schedule.
Stay motivated.
• Vary your routine—swim one day and mountain bike the next.
• Challenge your strength or endurance once or twice a week and do moderate workouts on other days.
• Track your progress by recording your activity.
• Reward your success with a new book, movie, or new workout clothes.
Keep your exercise safe.
• Warm up before you start and cool down when you are done.
• Wear light-colored or reflective clothing that is appropriate for the environmental conditions.
• Don't overdo it—alternate hard days with easy days and take a day off when you need it.
• Listen to your body so you stop before an injury occurs.

the body to dissipate heat while providing protection from the cold. For swimmers, cold water can cause performance to deteriorate.

Tailor Exercise Frequency, Intensity, and Duration Individuals should structure their fitness program based on their needs, goals, and abilities. For example, some people might prefer a short, intense workout such as 30 minutes of running, while others would rather work out for a longer time, at a lower intensity, such as a one-hour walk. Some may choose to complete all their exercise during the same session, while others may spread their exercise throughout the day, in shorter bouts. Three short bouts of 10-minute duration can be as effective as a continuous bout of 30 minutes in reducing the risk of chronic disease.[5] A combination of intensities, such as a brisk 30-minute walk twice during the week in addition to a 20-minute jog on two other days, can meet recommendations. Also, what is best for a middle-age man trying to reduce his risk of chronic disease is different from what is best for a 19-year-old college basketball player, and different still from what is best for an octogenarian trying to continue living independently. Young healthy athletes may require very intense activity to obtain a training effect. Older adults and those who have not previously been active can increase their fitness by exercising at a lower intensity if the duration and frequency of exercise are increased.

Don't Overdo It To improve cardiorespiratory fitness and muscle strength, the body must be stressed and respond to the stress by increasing aerobic capacity and muscle size and strength. Initially, training can cause fatigue and weakness, but during rest, the body rebuilds to become stronger. If not enough rest occurs between exercise sessions, there is no time to regenerate, so fitness and performance do not improve. In athletes, excessive training without sufficient rest to allow for recovery can lead to **overtraining syndrome**. The most common symptoms of this condition are fatigue, performance decline, and mood disturbances.[19] Athletes may become moody, easily irritated, or depressed; experience altered sleep patterns; or lose their competitive desire and enthusiasm. It may take weeks or months to recover. In addition to the physical demands of training, psychological factors such as excessive expectations from a coach or family members, competitive stress, personal or emotional problems, and school- or work-related demands contribute to the development of overtraining syndrome. Overtraining syndrome occurs only in serious athletes who are training extensively, but rest is essential for anyone working to increase fitness.

overtraining syndrome A collection of emotional, behavioral, and physical symptoms that occurs when the amount and intensity of exercise exceed an athlete's capacity to recover.

aerobic metabolism Metabolism in the presence of oxygen. In aerobic metabolism, glucose, fatty acids, and amino acids are completely broken down to form carbon dioxide and water and produce ATP.

anaerobic metabolism or **anaerobic glycolysis** Metabolism in the absence of oxygen. Each molecule of glucose generates two molecules of ATP. Glucose is metabolized in this way when the blood cannot deliver oxygen to the tissues quickly enough to support aerobic metabolism.

13.3 Exercise and Energy Metabolism

LEARNING OBJECTIVES

- Compare the fuels used to generate ATP by anaerobic and aerobic metabolism.
- Discuss the effect of exercise duration and intensity on the type of fuel used.
- Describe the physiological changes that occur in response to exercise.

Whether your goal is maintaining health or competing in athletic events, nutrition provides a launching pad from which physical fitness can be improved. Just as an automobile engine runs on energy from gasoline, the body machine runs on energy from the carbohydrate, fat, and protein in food and body stores. These fuels are needed whether you are writing a letter, walking around the block, or running a marathon. But before nutrients can be used to fuel activity, their energy must be converted into the high-energy compound ATP. ATP provides an immediate source of energy for all body functions, including muscle contraction. ATP can be generated both in the presence of oxygen by **aerobic metabolism** and in the absence of oxygen by **anaerobic metabolism** or **anaerobic glycolysis**. The way ATP is produced during activity depends on how long an activity is performed, the intensity of the activity, and the physical conditioning of the exerciser. This in turn affects how much carbohydrate, fat, and protein are used to produce this ATP.

How Exercise Duration Affects Metabolism

Resting muscles do not need much energy. At rest, the heart and lungs are able to deliver enough oxygen to meet energy demands using aerobic metabolism. During exercise, to increase the amount of energy provided by aerobic metabolism, the amount of oxygen available at the muscle must be increased (Figure 13.11). To do this, breathing and heart rate are increased, but this

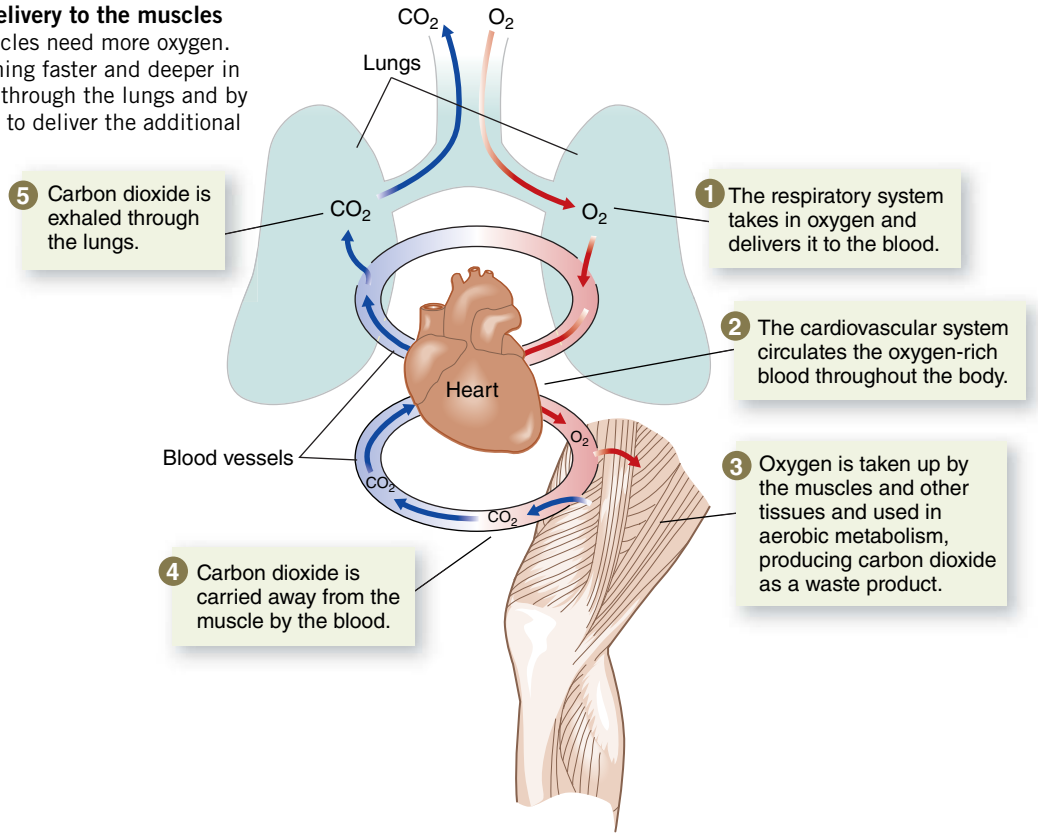


FIGURE 13.11 Oxygen delivery to the muscles When you exercise, your muscles need more oxygen. Your body responds by breathing faster and deeper in order to take in more oxygen through the lungs and by increasing heart rate in order to deliver the additional oxygen to your muscles.

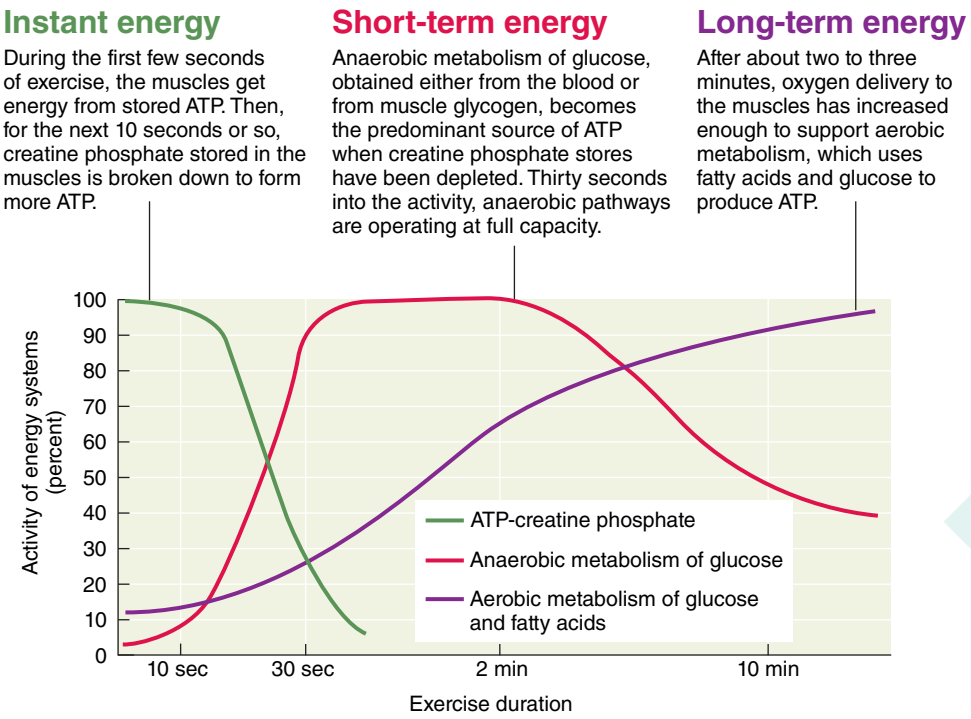


FIGURE 13.12 Changes in the source of ATP over time
The source of the ATP that fuels muscle contraction changes over the first few minutes of moderate-intensity exercise.

ANALYZE THE DATA

After about 10 minutes of moderate exercise, which ATP-producing system is operating at highest capacity?

takes time. When exercise first begins, breathing and heart rate have not yet had enough time to increase the amount of oxygen available at the muscle.

Instant Energy: Stored ATP and Creatine Phosphate When you jump up to answer the phone or take the first steps of your morning jog, your muscles increase their activity but your heart and lungs have not had time to step up oxygen delivery to them. To get the needed energy, the muscles rely on small amounts of ATP that are stored in resting muscle. It is enough to sustain activity for a few seconds. As the ATP in muscle is used, enzymes break down another high-energy compound, called **creatine phosphate** or **phosphocreatine**, to replenish the ATP supply and allow activity to continue. But, like ATP, the amount of creatine phosphate stored in the muscle at any time is small. It will fuel muscle activity for about an additional 8 to 10 seconds before it, too, is used up. So, during the first 10 to 15 seconds of exercise, the muscles rely on energy from the ATP and creatine phosphate that is stored in them (Figure 13.12).

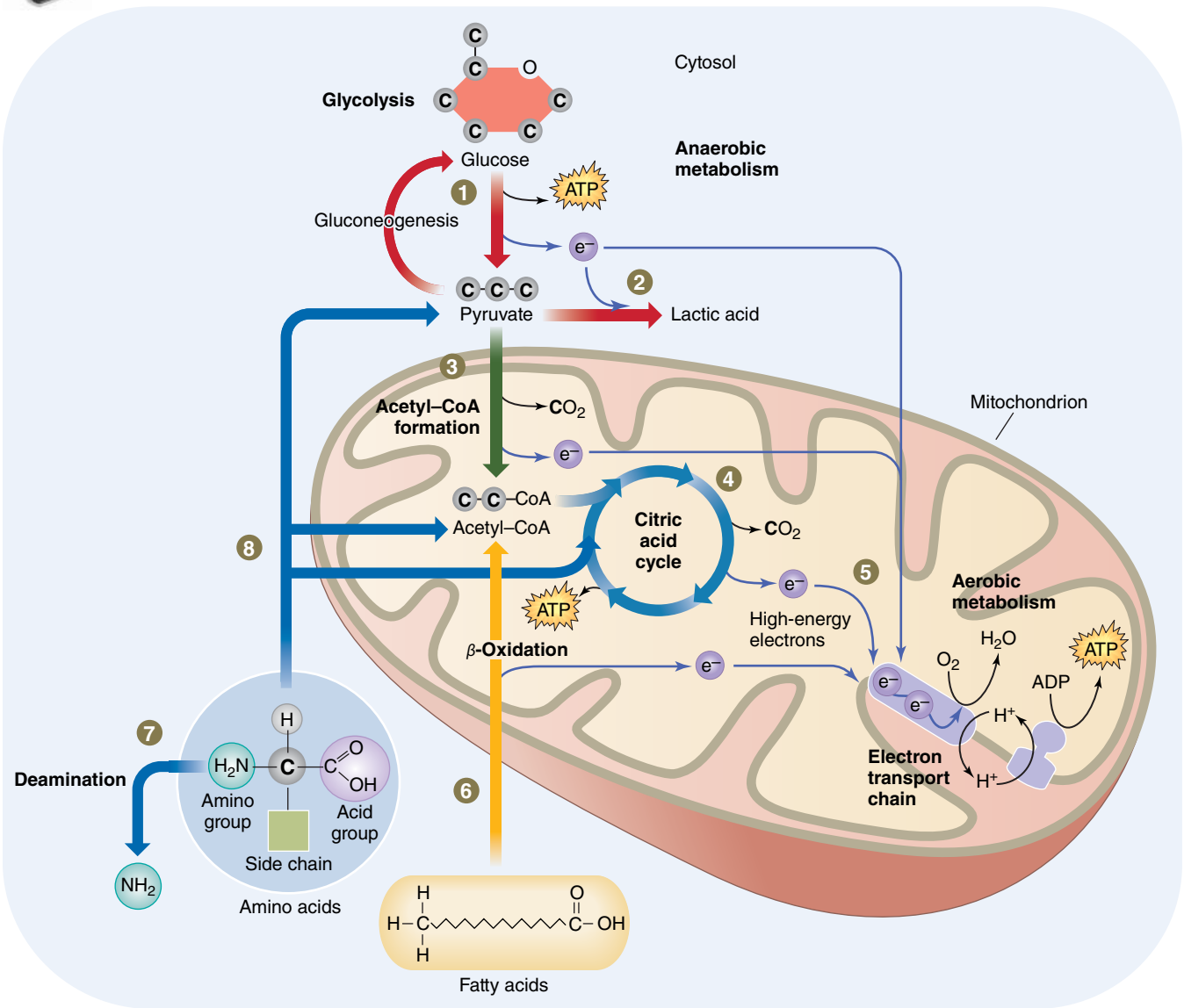
creatine phosphate or **phosphocreatine** A compound found in muscle that can be broken down quickly to generate ATP.

Short-Term Energy: Anaerobic Metabolism As exercise continues beyond 10 to 15 seconds, the ATP and creatine phosphate in the muscles are used up but the heart and lungs have still not had time to increase oxygen delivery to the muscles. Therefore, the additional ATP needed to fuel muscle contraction must be produced without oxygen. By 30 seconds into activity, anaerobic pathways are operating at full capacity (see Figure 13.12). This anaerobic metabolism takes place in the cytosol where glycolysis breaks glucose into the three-carbon molecule pyruvate, releases electrons, and produces two molecules of ATP (Figure 13.13). At this point, if oxygen is unavailable, the pyruvate and released electrons combine to form **lactic acid**. The lactic acid is transported out of the muscle for use in other tissues.

lactic acid A compound produced from the breakdown of glucose in the absence of oxygen.

Anaerobic metabolism can produce ATP very rapidly, but can only use glucose as a fuel. This glucose may come from the breakdown of glycogen inside the muscle or from glucose delivered via the bloodstream. The glucose delivered in the blood comes from the breakdown of liver glycogen, the synthesis of glucose by the liver, or the ingestion of

FIGURE 13.13 Anaerobic versus aerobic metabolism
In the absence of oxygen, ATP is produced by the anaerobic glycolysis of glucose. When oxygen is present, aerobic metabolism can use fatty acids and amino acids, as well as glucose to produce ATP.



1. Glucose is split into two molecules of pyruvate, releasing electrons, and producing two molecules of ATP.
2. In the absence of oxygen, the pyruvate and released electrons combine to form lactic acid.
3. When oxygen is available, the pyruvate is converted to acetyl-CoA.
4. Acetyl-CoA is broken down by the citric acid cycle.
5. The high-energy electrons released from all steps are shuttled to the electron transport chain, where their energy is harnessed to convert ADP to ATP.
6. β-Oxidation breaks fatty acids into two-carbon units, releasing high-energy electrons and forming acetyl-CoA.
7. Amino acids are deaminated before they can be used as an energy source.
8. After deamination, amino acids can be broken down to produce ATP. Some can be used to synthesize glucose by gluconeogenesis.

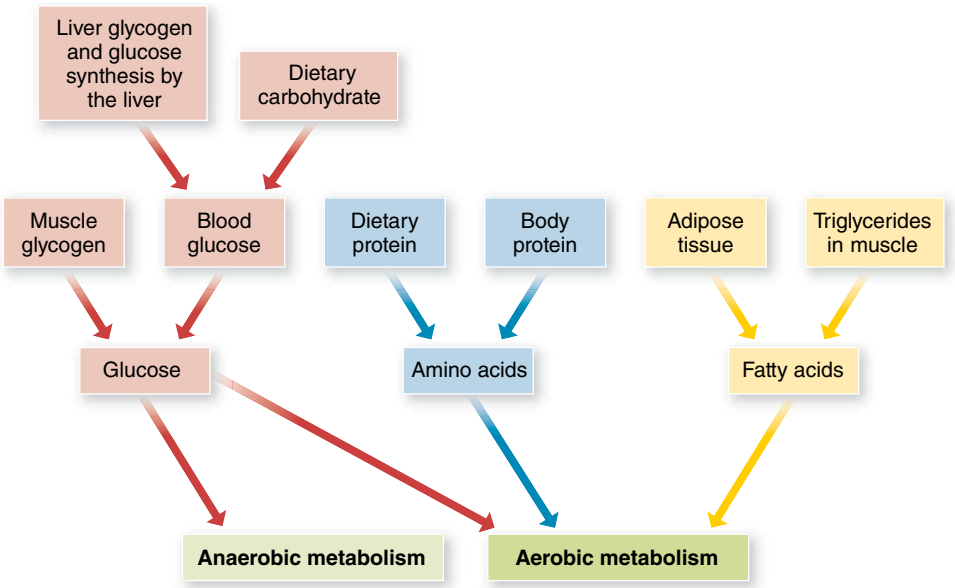


FIGURE 13.14 Fuels for anaerobic and aerobic metabolism
Glucose for anaerobic and aerobic metabolism can come from muscle glycogen or blood glucose. Aerobic metabolism uses fatty acids and amino acids as well as glucose to produce ATP.

carbohydrate during exercise (Figure 13.14). Anaerobic metabolism predominates during the first few minutes of exercise (see Figure 13.12) and is also important during periods of intense exercise because oxygen cannot be delivered to the cells quickly enough to meet energy demands. Anaerobic metabolism uses glucose rapidly. Because the amount of glucose available is limited, if activity is to continue, the body must use its glucose more efficiently and find a more plentiful fuel source.

Long-Term Energy: Aerobic Metabolism After two to three minutes of exercise, breathing and heart rate have increased to supply more oxygen to the muscles. When oxygen is available, ATP can be produced by aerobic metabolism. The reactions of aerobic metabolism take place in the mitochondria (see Figure 13.13). When glucose is broken down by aerobic metabolism, the pyruvate produced by glycolysis is converted to acetyl-CoA, so lactic acid is not formed. Acetyl-CoA is broken down by the citric acid cycle, producing carbon dioxide and some ATP and releasing high-energy electrons. The electrons are shuttled to the electron transport chain, where their energy is harnessed to convert ADP to ATP and water is formed.

Aerobic metabolism produces ATP more slowly than anaerobic metabolism but is much more efficient, producing about 18 times more ATP for each molecule of glucose. In addition, aerobic metabolism can use fatty acids, and sometimes amino acids from protein, to generate ATP (see Figures 13.13 and 13.14). Fatty acids to fuel muscle contraction come from triglycerides stored in adipose tissue as well as small amounts stored in the muscle itself. During exercise, triglycerides are broken down into fatty acids and glycerol. Fatty acids from adipose tissue are released into the blood and are then taken up by muscle cells. Inside muscle cells, fatty acids from triglycerides within the muscle and those delivered by the blood must be transported into the mitochondria to produce ATP. To enter the mitochondria, fatty acids must be activated with the help of **carnitine**. Inside the mitochondria, fatty acids are broken into two-carbon units by β-oxidation to form acetyl-CoA (see Figure 13.13). Acetyl-CoA is metabolized via the citric acid cycle and electron transport chain to produce ATP, carbon dioxide, and water.

carnitine A molecule synthesized in the body that is needed to transport fatty acids and some amino acids into the mitochondria for metabolism.

When exercise continues at a low to moderate intensity, aerobic metabolism predominates and fat becomes the principal fuel source for exercising muscles. If exercise intensity increases, the proportion of energy generated by anaerobic versus aerobic metabolism changes, as do the relative amounts of glucose and fatty acids used.

How Protein Is Used During Exercise Although protein is not considered a major energy source, even at rest the body uses small amounts of amino acids to provide energy. The amount

increases if the diet does not provide enough total energy to meet needs, if more protein is consumed than needed, if not enough carbohydrate is consumed, or if certain types of exercise are performed.

The amino acids available to the body come from the digestion of dietary proteins and from the breakdown of body proteins (see Figure 13.14). When the nitrogen-containing amino group is removed from an amino acid, the remaining carbon compound can be broken down to produce ATP by aerobic metabolism or in some cases used to make glucose via gluconeogenesis (see Chapter 4 and Figure 13.13). Endurance exercise, which continues for many hours, increases the use of amino acids both as an energy source and as a raw material for glucose synthesis. When exercise stops, amino acid use increases because protein synthesis is accelerated to build and repair muscle. Repeated activity with a slight overload stimulates the muscle to adapt to the stress by breaking down existing muscle proteins and replacing them with greater amounts of new muscle proteins to meet the higher demand placed on the muscle. The need for amino acids for muscle building and repair is greater in strength athletes because they are actively overloading their muscles to stimulate the synthesis of new muscle tissue.

How Exercise Intensity Affects Metabolism

During exercise, ATP is produced by both anaerobic and aerobic metabolism. Together, the contributions made by each of these systems ensure that muscles get enough ATP to meet the demand placed on them. The relative contribution of anaerobic versus aerobic metabolism depends on how intense the activity is. With very intense activity, the ability to deliver and use oxygen at the muscle becomes limiting. When the amount of ATP that can be produced by aerobic metabolism cannot meet the demand, the proportion of ATP produced anaerobically from glucose increases. Generally, the more intense the exercise, the more the muscles must rely on glucose to provide energy (**Figure 13.15A**). When intensity reaches the aerobic capacity of the athlete, most energy is derived from anaerobic metabolism of glucose. When the exercise is lower in intensity, the cardiorespiratory system can deliver enough oxygen to the muscles to allow aerobic metabolism to predominate, so fatty acids as well as some glucose are used as fuel. Thus, exercise intensity determines the contributions that carbohydrate and fat make as fuels for ATP production as well as the total number of calories burned (**Figure 13.15B**). In turn, which fuels are used affects how long exercise can continue before **fatigue** occurs.

fatigue The inability to continue an activity at an optimal level.

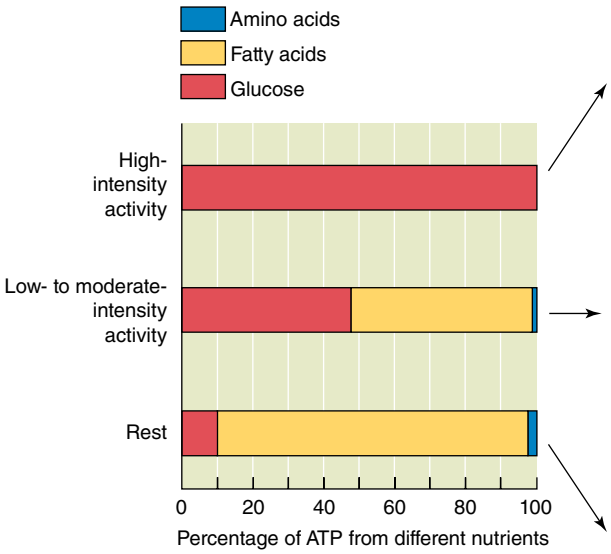
Exercise Intensity and Fatigue

Fatigue has many causes, including glycogen depletion, increased muscle acidity, and other changes in the muscle cells and the concentrations of molecules involved in muscle energy metabolism.[20,21] Fatigue occurs much more quickly with higher-intensity exercise than with lower-intensity exercise because more intense exercise relies more on anaerobic metabolism, which can use only glucose for fuel. Glycogen stores thus are rapidly depleted. Higher-intensity exercise also generates more heat and other by-products of metabolism, including lactic acid, than lower-intensity exercise. With low-intensity exercise, the small amounts of lactic acid produced are carried away from the muscles and used by other tissues as an energy source or converted back into glucose by the liver. During high-intensity exercise, the amount of lactic acid produced exceeds what can be used by other tissues, and the lactic acid builds up in the muscle and subsequently in the blood. Lactic acid buildup accompanies exercise-associated muscle fatigue, but it is not known to what extent lactic acid causes fatigue.[20,22] When exercise stops and oxygen is available again, lactic acid can be either carried away by the blood to other tissues to be broken down or metabolized aerobically in the muscle.

Why Low-Intensity Exercise Can Continue Longer

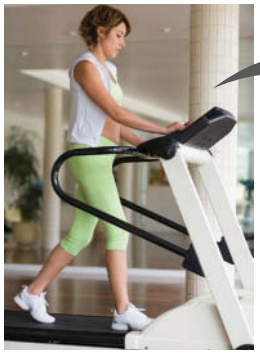
Lower-intensity exercise can be continued for longer periods because it relies on aerobic metabolism, which is more efficient than anaerobic metabolism and uses both glucose and fatty acids for energy. The body's fat reserves are almost unlimited, so that if fat is the fuel, exercise can theoretically continue for a very long time. For example, it is estimated that a 130-lb woman has enough energy stored as body fat to run 1000 miles.[23] However, even aerobic activity uses some glucose, so if exercise continues long enough, glycogen stores will eventually be depleted and contribute to fatigue.

FIGURE 13.15 The effect of exercise intensity on fuel use and energy expenditure

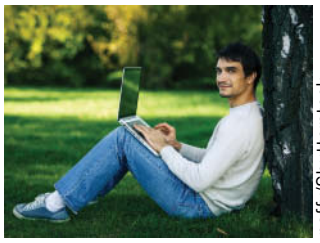


A. Exercise intensity determines the contributions of carbohydrate, fat, and protein as fuels for ATP production. At rest and during low- to moderate-intensity exercise, aerobic metabolism predominates, so fatty acids are an important fuel source. As exercise intensity increases, the proportion of energy supplied by anaerobic metabolism increases, so glucose becomes the predominant fuel. Keep in mind, however, that the total amount of energy expended per unit of time is greater as the intensity of exercise increases.

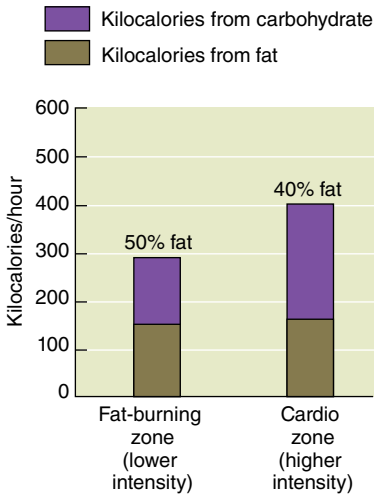
Rich Reid/NG Image Collection



RicGomez/Corbis Super RF/ Alamy Limited



paffy/Shutterstock



B. Aerobic exercise equipment typically includes workout programs that target your "fat-burning zone" and "cardio zone." Both are aerobic, but the fat-burning program is lower in intensity, so a higher proportion of fat is used for fuel. The higher-intensity cardio workout uses proportionately less fat, but the actual amount of fat used is the same and the total number of calories burned is greater.

ANALYZE THE DATA

Which workout will help you lose the most weight: 30 minutes in the cardio zone or 30 minutes in the fat-burning zone? Why?

When athletes run out of glycogen, they experience a feeling of overwhelming fatigue that is sometimes referred to as "hitting the wall" or "bonking." Glycogen depletion is a concern for athletes because the amount of glycogen available to produce glucose during exercise is limited. The liver can store between 60 and 120 g of glycogen; stores are highest just after a meal. Liver glycogen is used to maintain blood glucose between meals and during the night. Eating breakfast replenishes the liver glycogen used overnight. The muscles of a 150-lb person contain about 200 to 500 g of glycogen. The glycogen in a muscle is used to fuel the activity of that muscle. To delay fatigue, muscle glycogen levels can be increased by a combination of rest and a very-high-carbohydrate diet.

Why Training Increases Aerobic Capacity

Metabolism

Training with repeated bouts of aerobic exercise causes physiological changes that increase aerobic capacity—the amount of oxygen that can be delivered to and used by the muscle cells (Figure 13.16).[24] This in turn affects the proportion of glucose versus fatty acids that can be used by the exercising muscle cells.

Regular aerobic exercise causes adaptations in the cardiorespiratory system. The heart becomes larger and stronger so that the stroke volume is increased. The number of capillary blood vessels in the muscles increases so that blood is delivered to muscles more efficiently. And the total blood volume and number of red blood cells expand, increasing the amount of hemoglobin so more oxygen can be transported to the muscle cells.

Training also causes changes at the cellular level that affect the ability of cells to use different types of fuel to produce ATP. The ability to store glycogen is increased by training, as are the number and size of muscle-cell mitochondria (see Figure 13.16). Because aerobic metabolism occurs in the mitochondria, having larger and more numerous mitochondria increases the cell's

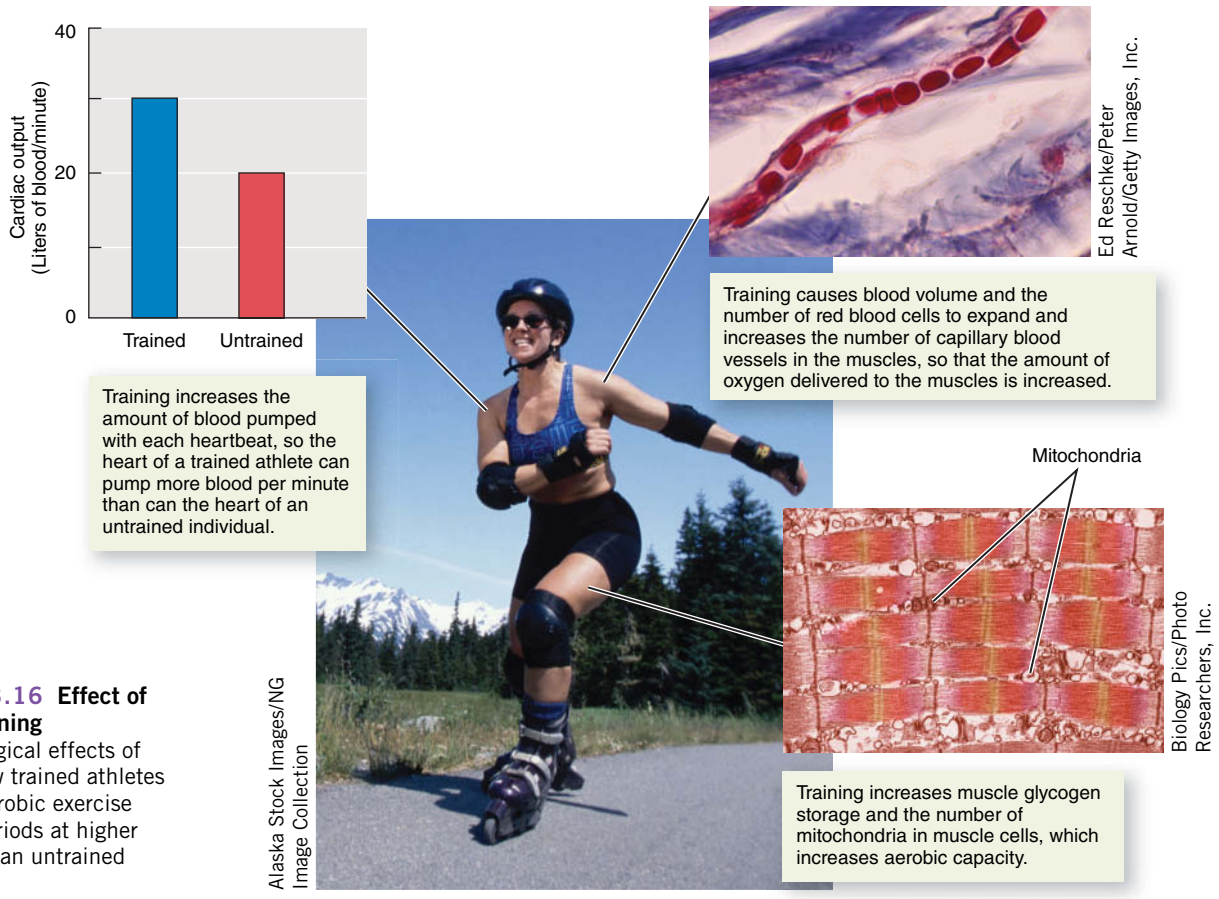


FIGURE 13.16 Effect of exercise training
The physiological effects of training allow trained athletes to sustain aerobic exercise for longer periods at higher intensities than untrained individuals.

capacity to burn fatty acids to produce ATP. The use of fatty acids spares glycogen, which delays the onset of fatigue. Because trained athletes store more glycogen and use it more slowly, they can sustain aerobic exercise for longer periods at higher intensities than can untrained individuals. Conditioned athletes can also exercise at a higher percentage of their aerobic capacity before lactic acid begins to accumulate.

Living and working at high altitudes, where the atmosphere contains less oxygen, also causes adaptations that improve the ability of the cardiorespiratory system to deliver oxygen. Therefore, endurance athletes often train at high altitudes to enhance their aerobic capacity.

13.4 Energy and Nutrient Needs for Physical Activity

LEARNING OBJECTIVES

- List factors that affect the energy needs of athletes.
- Discuss problems that may arise in athletes who restrict energy intake.
- Compare the carbohydrate, fat, and protein needs of athletes and nonathletes.
- Explain why athletes are at risk for iron deficiency.

Good nutrition is essential to performance, whether you are a marathon runner or a mall walker. The diet must provide sufficient energy from the appropriate sources to fuel activity, protein to maintain muscle mass, micronutrients to allow utilization of the energy-yielding nutrients, and water to transport nutrients and cool the body. The major difference between the nutritional needs of a serious athlete and those of a casual exerciser is the amount of energy and water required.

TABLE 13.2 Energy Needs for Various Activities

Body Weight		100 lb	125 lb	140 lb	155 lb	170 lb	185 lb	200 lb
Activity	**Rate**	**Energy (kcal/hr)**						
Bicycling	< 10 mph	137	171	191	212	233	252	273
	10–11.9 mph	228	285	318	353	388	420	455
	12–13.9 mph	319	399	445	494	543	588	637
	14–15.9 mph	410	513	572	635	698	756	819
	16–19 mph	501	627	699	776	853	924	1001
Running	12 min/mile	319	399	445	494	543	588	637
	10 min/mile	410	513	572	635	698	756	819
	8 min/mile	523	713	730	811	891	966	1047
	6 min/mile	683	855	953	1058	1163	1260	1365
Skiing, cross-country	2.5 mph	273	342	381	423	465	504	546
	4–4.9 mph	319	399	445	494	543	588	637
	5–7.9 mph	364	456	508	564	620	672	728
Swimming	Leisurely	228	285	318	353	388	420	455
	50 yd/min	319	399	445	494	543	588	637
	75 yd/min	455	570	635	705	775	840	910
Walking	2 mph	68	86	95	106	116	126	137
	3 mph	105	131	146	162	178	193	209
	4 mph	182	228	254	282	310	336	364

Energy Needs

The amount of energy needed for activity depends on the intensity, duration, and frequency of the activity, as well as on the characteristics of the exerciser, and even his or her location. For a casual exerciser, the energy needed for activity may increase energy expenditure by only a few hundred kilocalories a day. For an endurance athlete, such as a marathon runner, the energy needed for training may increase expenditure by 2000 to 3000 kcal/day. Some athletes require 6000 kcal/day to maintain body weight. In general, the more intense the activity, the more energy it requires, and the more time spent exercising, the more energy it burns (Table 13.2 and Appendix D). For example, walking for 30 minutes involves less work than running for the same amount of time and therefore requires less energy. Riding a bicycle for 60 minutes requires six times the energy needed to ride for 10 minutes. The body weight of the exerciser is another factor in determining energy needs. Moving a heavier body requires more energy than moving a lighter one. Therefore, it requires less energy for a 120-lb woman to walk for 30 minutes than for a 200-lb woman.

As discussed in Chapter 7, the DRI equations used to estimate energy requirements are based on an individual's age, gender, size, and physical activity (PA) level (see inside cover). To maintain a healthy body weight and fully achieve the health benefits of exercise, it is recommended that adults perform enough activity to be considered active or very active (see Figure 7.19). An "active" PA category can be achieved by engaging in 60 minutes of moderate exercise each day and can be achieved with less than 60 minutes of exercise per day if the exercise is more intense, for example, jogging at 5 mph or greater or swimming at a moderate to fast pace. Individuals who perform moderate exercise for more than 2.5 hours per day or more intense exercise for more than 1.25 hours per day are in the "very active" PA category. Calculating estimated energy requirement (EER) at different activity levels can demonstrate the dramatic impact activity can have on energy needs. For example, the EER for a 25-year-old, sedentary, 5′11″ tall, 160-lb man is about 2500 kcal. If this same person becomes a runner and trains several hours per day, his energy needs may increase to 3500 kcal/day or more (Figure 13.17).

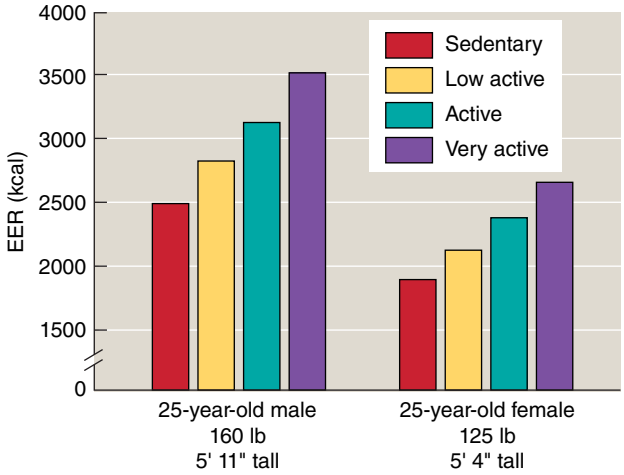


FIGURE 13.17 Effect of activity level on energy expenditure
Your routine activity level determines whether you are in the sedentary, low-active, active, or very active category and significantly affects the number of calories you need to consume each day to maintain body weight.

There are also some special considerations that affect the energy needed for activity. For example, because of the buoyancy of adipose tissue, the energy required for an individual with excess body fat to swim may be less than that of his lean counterpart. If a lean individual and an obese individual were in the weightlessness of space, both would require the same amount of energy to leap across the room. There are also special circumstances that affect the amount of energy an individual needs for daily activity. An individual with paraplegia may have lower energy needs because many of the major muscles in the body are always inactive. At the other extreme, a person with the form of cerebral palsy that causes uncontrolled muscle movements may have higher energy needs because the muscles never stop moving.

Healthy Weight Loss Body weight and composition can affect exercise performance. In sports such as ballet, gymnastics, and certain running events, small, light bodies offer an advantage, so athletes may restrict energy intake in order to maintain a low body weight.

Athletes who want to lose weight should follow the general guidelines for healthy weight loss—reduce energy intake, increase activity, and change the behaviors that led to weight gain (see Chapter 7). To preserve lean body mass and enhance fat loss, weight should be lost slowly, at a rate of about 0.5 to 2 lb/week. This can be accomplished by reducing total energy intake by 200 to 500 kcal/day and increasing activity. An athlete who needs to lose weight should do so in advance of the competitive season to prevent the restricted diet from affecting performance.[25]

Unhealthy Weight-Loss Practices Athletes are often under extreme pressure to achieve and maintain a body weight that optimizes their performance. Failure to meet weight-loss goals may have serious consequences, such as being cut from the team or restricted from competition. This pressure may compel some athletes to use strict diets and maintain body weights that are so low that health and performance are threatened.

female athlete triad The combination of energy restriction, menstrual irregularities, and low bone density that occurs in some female athletes, particularly those involved in sports in which low body weight and appearance are important.

Making Weight Athletes involved in sports with weight classes, such as wrestling and boxing, are at particular risk for unhealthy weight-loss practices because they are under pressure to lose weight before a competition so they can compete in lower weight classes. Competing at the high end of a weight class is thought to give one an advantage over smaller opponents. To lose weight rapidly, these athletes may use sporadic diets that severely restrict energy intake or dehydrate themselves through such practices as vigorous exercise, fluid restriction, wearing plastic vapor-impermeable suits, and using hot environments such as saunas and steam rooms. They may also resort to even more extreme measures, such as self-induced vomiting and the use of diuretics and laxatives. These practices can be dangerous and even fatal (Figure 13.18). They may impair performance and can adversely affect heart and kidney function, temperature regulation, and electrolyte balance.

Enigma/Alamy

FIGURE 13.18 Making weight
After three young wrestlers died while exercising in plastic suits in order to sweat off water, wrestling guidelines were changed to improve safety. Unsafe weight-loss practices such as the use of saunas and vapor-impermeable suits and excessive food and fluid restriction were banned, weigh-ins were moved to one hour before competition, and mandatory weight-loss rules were instituted. The percentage of body fat can be no less than 5% for college wrestlers.[26]

Female Athlete Triad Energy restriction in female athletes can result in the **female athlete triad**. The female athlete triad occurs when low energy intake combined with exercise results in hormonal abnormalities that affect calcium and bone metabolism and can lead to bone loss. It can progress from a triad of low energy availability, menstrual dysfunction, and low bone mineral density to a clinical eating disorder, amenorrhea, and osteoporosis (see Focus on Eating Disorders).[27] Hormonal abnormalities occur when extreme energy restriction and exercise create a physiological condition similar to starvation. Estrogen levels drop, causing amenorrhea. Because estrogen is needed for calcium homeostasis in the bone and calcium absorption in the intestines, low levels lead to premature bone loss, low peak bone mass, and an increased risk of stress fractures.[28] Neither adequate dietary calcium nor the increase in bone mass caused by weight-bearing exercise can compensate for

bone loss due to low estrogen levels. Treatment for female athlete triad involves increasing energy intake and reducing activity so that menstrual cycles resume. This is essential for preserving long-term bone health.

Recently it has been suggested that the concept of the female athlete triad be expanded to a broader syndrome that applies to both females and males called *Relative Energy Deficiency in Sport (RED-S).*[29] The limited energy availability in RED-S affects not only menstrual function and bone health, but also metabolic rate, immunity, protein synthesis, growth and development, and cardiovascular and psychological health.

Eating Disorders The pressure to maintain a low body weight along with the motivation and self-discipline characteristic of successful athletes contribute to an increased risk of eating disorders among athletes.[30] In those with anorexia, restricted food intake causes a deficiency of energy and nutrients, which can affect growth and maturation and impair exercise performance. In athletes with bulimia, purging can cause dehydration and electrolyte imbalance, which affect performance and put overall health at risk. In addition to using restricted food intake or purging to keep body weight low, some athletes focus on the other side of the energy balance equation by exercising compulsively to burn calories (see Focus on Eating Disorders).

Healthy Weight Gain In sports such as football and weightlifting, having a large amount of muscle is advantageous, and athletes may try to build muscle and increase body weight. Adding weight and muscle mass can enhance performance and help to protect athletes in contact sports like football and hockey. Healthy weight gain, however, like weight loss, takes time. A weight gain of 0.5 to 1 lb per week can be accomplished by slowly increasing portion sizes and adding frequent snacks to increase calorie intake by 500 to 1000 kcal/day. These extra calories can include healthy choices from each food group of MyPlate. Increasing calories from high-fat, high-sugar snacks and beverages will increase calorie intake, but will decrease the nutrient density of the diet.

Strength training is an essential part of weight gain for athletes. It will stimulate appetite and also promote an increase in lean tissue. Additional calories along with muscle-building exercise will help maximize lean weight gain and minimize weight gain from fat. Adequate protein intake is essential for increasing muscle mass, but most of the energy needed to fuel muscle growth comes from carbohydrate and fat, so protein supplements and very high-protein diets are unnecessary.

Carbohydrate, Fat, and Protein Needs

The source of dietary energy can be as important as the amount of energy in an athlete's diet. In general, the diets of physically active individuals should contain the same proportion of carbohydrate, fat, and protein as is recommended to the general public—about 45 to 65% of total energy as carbohydrate, 20 to 35% of energy as fat, and 10 to 35% of energy as protein (Figure 13.19).

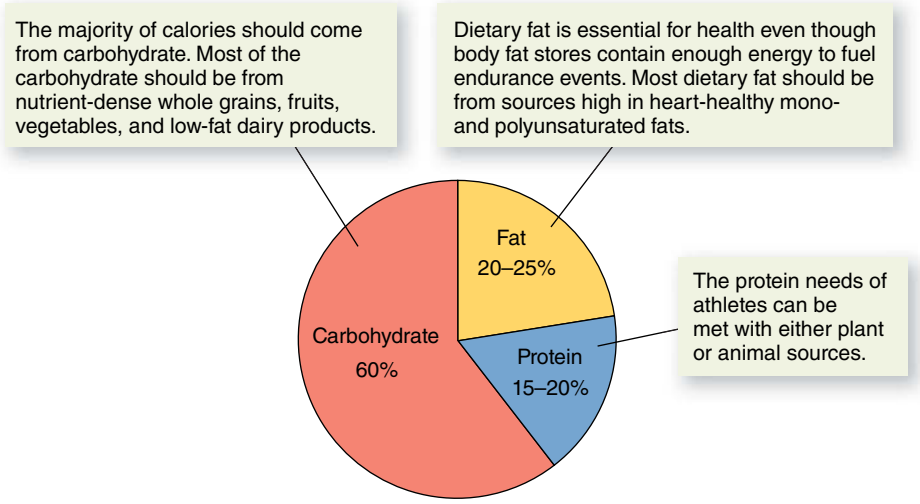


FIGURE 13.19 Proportions of energy-yielding nutrients in an athlete's diet
The proportions of carbohydrate, fat, and protein recommended in the diets of athletes, shown in the pie chart, are within the ranges recommended for the general public.

Carbohydrate Carbohydrate is needed to maintain blood glucose levels during exercise and to replace glycogen stores after exercise. The amount recommended for athletes depends on the total energy expenditure, type of sport, gender, and environmental conditions, but ranges from 6 to 10 g/kg of body weight per day.[25] For a 150-lb person burning 3000 kcal/day, this would be about 60% of calories, or about 450 g of carbohydrate. Most of the carbohydrate in the diet should be complex carbohydrates from whole grains and starchy vegetables, with some naturally occurring simple sugars from fruit and milk. These foods provide vitamins, minerals, phytochemicals, and fiber as well as energy. Snacks and meals consumed before or during exercise should be lower in fiber to avoid cramping and gastrointestinal distress.

Fat Dietary fat supplies essential fatty acids, ensures the absorption of fat-soluble vitamins, and provides an important source of energy. Body stores of fat provide enough energy to support the demands of even the longest endurance events. The amount of fat recommended for physically active individuals is the same as for the general population: 20 to 35% of energy with limited amounts of saturated and *trans* fat.[14,25] Diets higher in fat may not contain enough carbohydrate to maximize glycogen stores and optimize performance. Excess dietary fat is unnecessary and excess energy consumed as fat, carbohydrate, or protein can cause an increase in body fat. Diets very low in fat (less than 20% of calories) have not been found to benefit performance.

Protein Protein is not a significant energy source, accounting for only about 5 to 10% of energy expended, but dietary protein is needed to maintain and repair lean tissues, including muscle. Enough protein is essential to maintain muscle mass and strength, but eating extra protein does not produce bigger muscles. A diet in which 15 to 20% of calories come from protein will meet the needs of most athletes. This protein can come from plant sources such as legumes, grains, and nuts, and/or animal sources such as lean meat, fish, eggs, and low-fat dairy products.

A diet that contains the RDA for protein (0.8 g/kg) provides adequate protein for most active individuals. As discussed in Chapter 6, competitive athletes participating in endurance and strength sports may require more protein.[25] In endurance events such as marathons, protein is used for energy and to maintain blood glucose, so these athletes may benefit from 1.2 to 1.4 g of protein per kilogram per day. Strength athletes who require amino acids to synthesize new muscle proteins may benefit from 1.2 to 1.7 g/kg per day (see **Critical Thinking: Getting Enough Protein**). While this amount is greater than the RDA, it is not greater than the amount of protein habitually consumed by athletes.[31] For example, a 185-lb man (84 kg) consuming 3000 kcal/day, 18% of which is from protein, would be consuming 135 g of protein, or 1.6 g/kg of body weight.

Vitamin and Mineral Needs

An adequate intake of vitamins and minerals is essential for optimal performance. These nutrients are needed for energy metabolism, oxygen delivery, antioxidant protection, and repair and maintenance of body structures. During exercise, the amounts of many vitamins and minerals used in energy metabolism are increased, and after exercise the amounts of those needed to repair tissue damage are increased. Exercise may also increase the losses of some nutrients. Nonetheless, most athletes can meet their needs by consuming the amounts of vitamins and minerals recommended for the general population. In addition, because athletes must eat more food to satisfy their higher energy needs, they consume extra vitamins and minerals in these foods, particularly if nutrient-dense choices are made. Athletes who restrict their intake to maintain low body weight may be at greater risk for vitamin or mineral deficiencies.

B Vitamins B vitamins such as thiamin, riboflavin, and niacin are important for the production of ATP from carbohydrates and fat. Vitamin B_6, folate, and vitamin B_{12} are needed for proper synthesis of red blood cells, which deliver oxygen to body tissues. Vitamin B_6 is needed to break down glycogen to release glucose and to make the protein hemoglobin, which carries oxygen in red blood cells. Despite the importance of all of these roles during exercise, the recommended intake of B vitamins is no greater for athletes than for the rest of the population.

CRITICAL THINKING

Getting Enough Protein

© Leigh Schindler/iStockphoto

BACKGROUND

Paulo is a football player who weighs 240 lb and is planning on doing some weightlifting to put on about 20 lb of muscle before the season begins.

▼

Based on the RDA for a strength athlete, how much protein should Paulo consume per day?

Paulo has read that eating protein immediately after exercise and at other key times enhances the muscle protein synthesis that is stimulated by the weightlifting. So, he adds three protein shakes to his daily diet, one first thing in the morning, one right after lifting weights, and one before going to bed. The label from his protein shake is shown below.

Powdered Protein Shake Mix

Nutrition Facts

Serving Size 1 Scoop (28.5g)
Servings Per Container 30

Amount Per Serving	
Calories 110	**Calories from Fat** 20
	% Daily Value**
Total Fat 2g	3%
Saturated Fat 1g	5%
Cholesterol 30mg	10%
Sodium 40mg	2%
Potassium 197mg	6%
Total Carbohydrate 4g	1 %
Dietary Fiber 1g	4%
Sugars 2g	†
Protein 18g	36%

▼

How much protein will three scoops add to Paulo's diet? How many calories will it add?

Paulo recognizes that he can get high-quality protein from foods. However, it is sometimes difficult to have the food available right after his work out, when protein is important for muscle protein synthesis.

▼

How much low-fat milk would Paulo need to drink to get as much protein as three scoops of the protein powder? What about chicken—how many ounces of boneless skinless chicken breast would he need to eat?

CRITICAL THINKING QUESTIONS

- **The protein powder costs $22 per jar. Is it cheaper to use the supplement or get the protein from milk or chicken?**
- **Compare the supplement to food in terms of convenience.**
- **Assuming his current diet provides 100 g of protein, are there any health risks associated with consuming the extra protein from the powder?**
- **What would you recommend to Paulo?**

iProfile Use iProfile to find other high-protein foods Paulo could add in place of the protein powder.

Antioxidant Nutrients and Oxidative Damage Exercise increases the amount of oxygen at the muscle and the rate of ATP-producing metabolic reactions. This increased oxygen use increases the production of free radicals, which can lead to oxidative stress and contribute to muscle fatigue.[32] To protect the body from damage caused by free radicals, muscle cells contain antioxidant defenses, some of which may interact with dietary antioxidants such as vitamin C, vitamin E, β-carotene, and selenium. Despite the increase in free radical production that occurs during exercise, there is no evidence that supplementation of antioxidants improves performance or that athletes require more of these nutrients than the general public.[33]

Iron and Anemia Iron is a component of hemoglobin, which is needed for the delivery of oxygen to cells; myoglobin, which stores oxygen within muscle cells; and other iron-containing proteins that are essential for the production of ATP by aerobic metabolism. Exercise increases the need for these proteins and may thereby increase iron needs. For example, exercise stimulates the production of red blood cells, so more iron is needed for hemoglobin synthesis. There is also evidence that exercise reduces iron uptake from the GI tract, further increasing needs.[34]

Prolonged training may also contribute to iron deficiency by increasing iron losses in feces, urine, and sweat.[25] Another cause of iron loss is foot-strike hemolysis. This is the breaking of red blood cells due to the contraction of large muscles or impact in events such as running. Foot-strike hemolysis rarely causes anemia because most of the iron from these cells is recycled, and the breaking of red blood cells stimulates the production of new ones.

The increased iron needs and losses seen in athletes make iron deficiency a concern. Reduced iron stores are not uncommon in athletes.[25] Female athletes are at particular risk; their needs are higher than those of male athletes because they need to replace the iron lost in menstrual blood.[34] Inadequate iron intake may also contribute to low iron stores in athletes of both genders who are attempting to keep their body weight down and/or do not eat meat, which is an excellent source of readily absorbable heme iron. If iron deficiency progresses to anemia, the body's ability both to transport oxygen and to provide energy by aerobic metabolism is reduced, impairing exercise performance as well as overall health. Although a specific RDA for iron has not been set for athletes, the DRIs acknowledge that, based on iron losses, the EAR may be 30 to 70% higher for athletes than for the general population.[35]

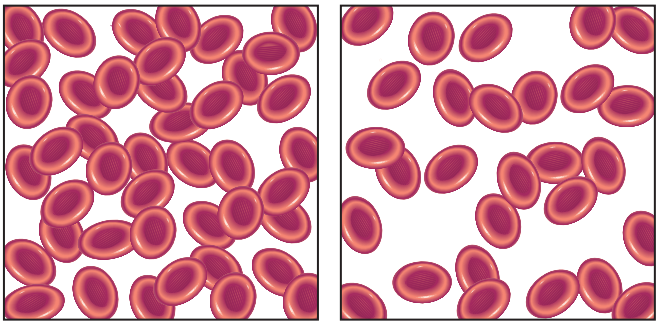


FIGURE 13.20 Sports anemia
Training causes a decrease in the percentage of blood volume that is red blood cells. As training progresses, the number of red blood cells increases to catch up with the increase in total blood volume.

Iron deficiency anemia (see Chapter 12) should not be confused with **sports anemia**, which is a temporary decrease in hemoglobin concentration that occurs during exercise training. This is an adaptation to training that does not seem to impair delivery of oxygen to tissues.[24] It occurs when blood volume expands to increase oxygen delivery, but the synthesis of red blood cells lags behind the increase in plasma volume (Figure 13.20).

sports anemia Reduced hemoglobin levels that occur as part of a beneficial adaptation to aerobic exercise in which expanded plasma volume dilutes red blood cells.

Calcium and Vitamin D Calcium and vitamin D are needed to maintain blood calcium levels and promote and maintain healthy bone density, which in turn reduces the risk of osteoporosis. In general, exercise—particularly weight-bearing exercise—increases bone density, thereby reducing the risk of osteoporosis, but this occurs only when levels of vitamins, minerals, and hormones are adequate.

An athlete's diet should include adequate sources of calcium to maintain bone health. The additional energy needs of athletes allow calcium sources, such as a slice of cheese on a sandwich or a milkshake, to be added without exceeding energy needs. Even if the diet is adequate in calcium, it can't be absorbed efficiently without sufficient vitamin D (see Chapter 9). Vitamin D deficiency is a concern in athletes because it can contribute to stress fractures and possibly impair muscle function and athletic performance.[36] Since vitamin D can be synthesized in the skin from sun exposure, status is generally higher in outdoor than indoor

athletes. Athletes can usually achieve adequate vitamin D status during the summer, spring, and fall, but during the winter, vitamin D supplements may be needed to attain adequate blood levels of vitamin D.[37]

13.5 Fluid Needs for Physical Activity

LEARNING OBJECTIVES

- Discuss dehydration in relation to performance and heat-related illness.
- Describe an exercise scenario that might lead to hyponatremia.
- Explain why the types of fluid recommended for a 30-minute workout and a two-hour workout are different.

heat-related illnesses Conditions, including heat cramps, heat exhaustion, and heat stroke, that can occur due to an unfavorable combination of exercise, hydration status, and climatic conditions.

hypothermia A condition in which body temperature drops below normal. Hypothermia depresses the central nervous system, resulting in the inability to shiver, sleepiness, and eventually coma and death.

During exercise, water is needed to eliminate heat and to transport both oxygen and nutrients to the muscles and waste products away from the muscles. The ability to dissipate the heat generated during exercise is affected by the hydration status of the exerciser as well as by environmental conditions. At rest in a temperate environment, an individual loses about 1.2 L (about 5 cups) of water per day, or 50 mL per hour, through evaporation from the skin and lungs. Exercise in a hot environment can increase losses more than 10-fold. Even when fluids are consumed at regular intervals during exercise, it may not be possible to drink enough to compensate for losses from sweat and evaporation through the lungs. Failure to consume adequate fluids to replace water lost can be critical for even the most casual exerciser. If heat cannot be lost from the body, body temperature rises and health as well as exercise performance may be jeopardized.

How Dehydration Affects Health and Performance

Dehydration occurs when water loss is great enough for blood volume to decrease, thereby reducing the ability to deliver oxygen and nutrients to exercising muscles. Dehydration hastens the onset of fatigue and makes a given exercise intensity seem more difficult. Even mild dehydration—a body water loss of 2 to 3% of body weight—can impair exercise performance (Figure 13.21).[38] Dehydration reduces the amount of blood pumped with each heartbeat. This reduces the ability of the circulatory system to deliver oxygen and nutrients to cells and remove waste products. The decrease in blood volume that occurs with dehydration reduces blood flow to the skin and sweat glands, which limits the body's ability to produce sweat and cool itself. Core body temperature can then increase and with it the risk of various **heat-related illnesses**.

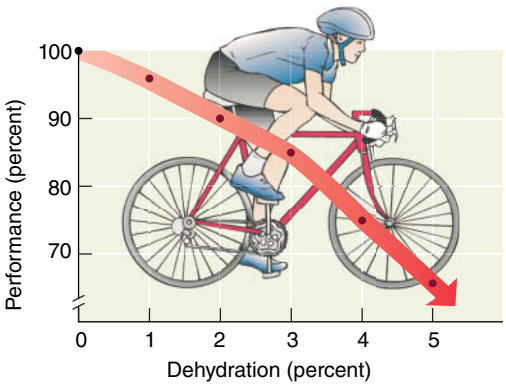


FIGURE 13.21 Effect of dehydration on exercise performance
As the severity of dehydration increases, exercise performance declines.[39]

The risk of dehydration is greater in hot environments, but it may also occur when exercising in the cold. Cold air tends to be dry air, so evaporative losses from the lungs are greater. Insulated clothing may increase sweat losses and fluid intake may be reduced because a chilled athlete may be reluctant to drink a cold beverage. Female athletes tend to limit fluid intake in the cold to avoid the inconvenience of removing clothing to urinate.[25]

LIFE CYCLE

Children, older athletes, and individuals who are obese are at a greater risk for dehydration and heat-related illness. Children produce more heat, are less able to transfer heat from muscles to the skin, take longer to acclimatize to heat, and sweat less than adults. To reduce risks on hot days, children should rest periodically in the shade, consume fluids frequently, and limit the intensity and duration of activities. Also, children lose more heat in cold environments than adults because they have a greater surface area per unit of body weight. Therefore, they are more prone to **hypothermia**.

Older athletes are at greater risk of dehydration because the thirst sensation decreases with age, and the kidneys may be less able to concentrate urine, thus increasing the amount of fluid lost in urine. Excess weight increases the risk of heat-related illness because it increases

the amount of work and therefore the amount of heat produced in a given activity. Body fat also acts as an insulator, retarding the conduction of heat to the body surface. Individuals who are obese also have a smaller surface-area-to-body-mass ratio than lean people, so they are less efficient at dissipating heat through blood flow to the surface and the evaporation of sweat.

Why Heat-Related Illness Is a Concern for Athletes

Exercising in hot weather can lead to heat-related illness. Heat-related illnesses include heat cramps, heat exhaustion, and heat stroke. Heat cramps are involuntary muscle spasms that occur during or after intense exercise, usually in the muscles involved in exercise. They are caused by an imbalance of the electrolytes sodium and potassium at the muscle cell membranes and can occur when water and salt are lost during extended exercise. Heat exhaustion occurs when fluid loss causes blood volume to decrease so much that it is not possible to both cool the body and deliver oxygen to active muscles. It is characterized by a rapid weak pulse, low blood pressure, fainting, profuse sweating, and disorientation. Someone experiencing the symptoms of heat exhaustion should stop exercising and move to a cooler environment. If exercise continues, heat exhaustion may progress to heat stroke. Heat stroke, the most serious form of heat-related illness, occurs when the temperature regulatory center of the brain fails due to a very high core body temperature (greater than 105°F). Heat stroke is characterized by elevated body temperature, hot dry skin, extreme confusion, and unconsciousness. It requires immediate medical attention.

Both temperature and humidity greatly affect the risk of heat-related illness. As environmental temperature rises, it becomes more difficult to dissipate heat and as humidity rises, the ability to cool the body by evaporation declines.[40] When the humidity is high, the same air temperature feels hotter than when the humidity is lower. For example, when the humidity is 100%, a temperature of 82°F feels the same as a temperature of 90°F and a humidity of only 50%. The risks associated with exercising in these conditions are similar (Figure 13.22). The risk of heat-related illness is increased in sports such as football that require protective clothing that interferes with heat dissipation from the body. Dehydration also increases the risk of heat-related illness because it reduces the ability to cool the body. Dehydration can precipitate

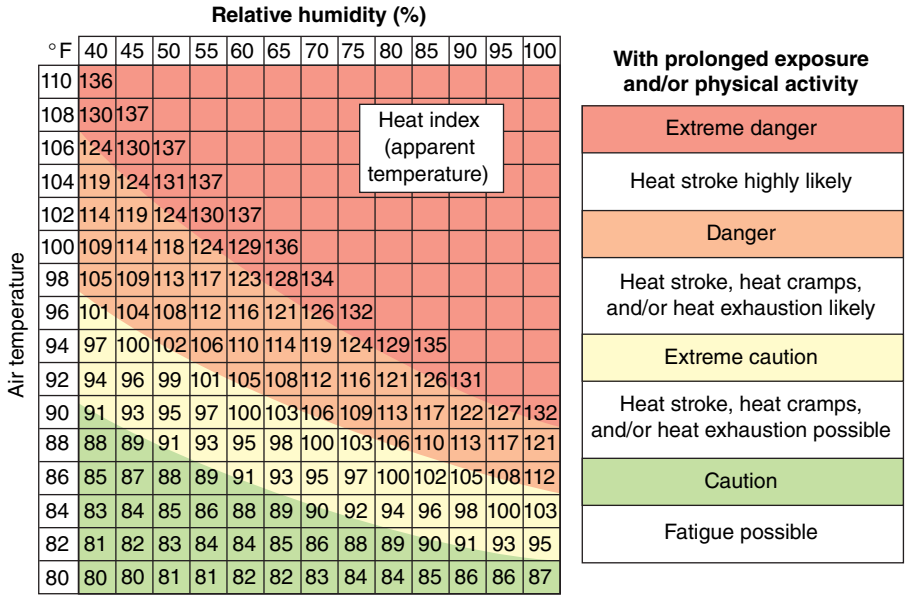


FIGURE 13.22 Heat index and the risk of heat-related illness[40]
The "heat index" or "apparent temperature" is a measure of how hot it feels when the relative humidity is added to the actual air temperature. To find the heat index, find the intersection of the temperature on the left side of the table and the relative humidity across the top of the table. The colored zones indicate the relative risk of heat-related illness with continued exposure and/or physical activity.

these disorders even when it is not extremely hot or humid. Conditioning with repeated bouts of exercise and adequate hydration can reduce the risk of heat-related illness.

Causes and Consequences of Hyponatremia

The evaporation of sweat helps cool the body during exercise. Sweat is a blood filtrate produced by sweat glands in the skin. It is made up of 99% water along with small amounts of minerals, primarily sodium and chloride, acids, and trace amounts of other substances. Because sweat is mostly water, for most activities sweat losses can be replaced with plain water. However, when sweating continues for more than four hours, as it may during endurance events such as marathons, enough sodium may be lost to affect electrolyte balance. A reduction in the concentration of sodium in the blood is referred to as **hyponatremia**. Hyponatremia can occur if an athlete loses large amounts of water and salt in sweat and replaces the loss with water alone. This causes the sodium that remains in blood to be diluted, so that the amount of water is too great for the amount of sodium. This is analogous to taking a full glass of salt water, dumping out half, and replacing what was poured out with plain water. The sodium in the glass is now more dilute (Figure 13.23). It is also possible to develop hyponatremia when salt losses from sweating are not excessive. This can occur if athletes drink more water than is lost in sweat, diluting the sodium in their system. A study of runners in the Boston marathon found that 13% of those tested had hyponatremia and 0.6% had serum sodium concentrations low enough for this condition to be considered critical.[41] It is the concentration of sodium that is important, not the absolute amount.

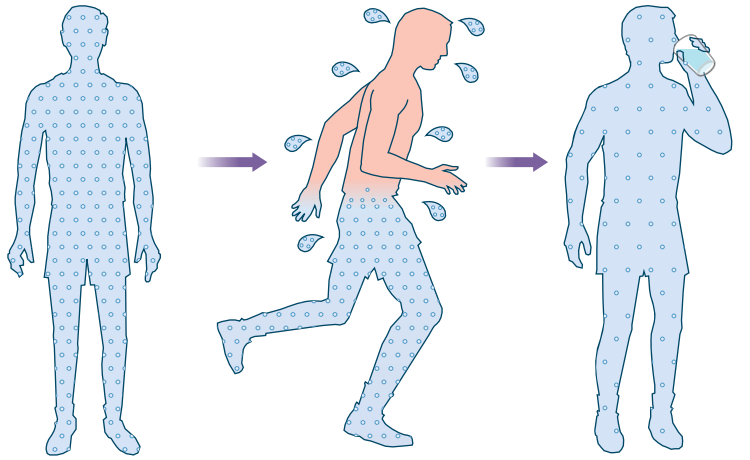


FIGURE 13.23 Hyponatremia
Hyponatremia can occur when an athlete loses water and sodium in sweat but replaces these losses with plain water, diluting the remaining sodium in the blood.

hyponatremia Abnormally low concentration of sodium in the blood.

Hyponatremia is dangerous because the sodium in the blood helps hold fluid in the blood vessels. As sodium concentration drops, water will leave the bloodstream by osmosis and accumulate in the tissues, causing swelling. Fluid accumulation in the lungs interferes with gas exchange, and fluid accumulation in the brain causes disorientation, seizure, coma, and death. The early symptoms of hyponatremia may be similar to dehydration: nausea, muscle cramps, disorientation, slurred speech, and confusion. Drinking water alone will make the problem worse and can result in seizure, coma, or death.

For most exercise, hyponatremia is not a concern and lost electrolytes can be replaced during the meals following exercise. During long-distance events when hyponatremia is more likely, risk can be reduced by increasing sodium intake several days prior to competition, consuming sodium-containing sports drinks during the event, and avoiding Tylenol, aspirin, ibuprofen, and other nonsteroidal anti-inflammatory agents. These medications interfere with kidney function and may contribute to the development of hyponatremia. Mild symptoms of hyponatremia can be treated by eating salty foods or drinking sodium-containing beverages such as sports drinks. More severe symptoms require medical attention.

Recommended Fluid Intake for Exercise

Anyone exercising needs extra fluids. Good hydration is important before exercise and during exercise to maximize performance. The amount and type of fluid that is best depends on how much water you lose and how long you exercise. Because many people do not consume enough during exercise, beverages consumed after exercise must restore hydration.

How Much Should You Drink? Starting exercise with a low body weight due to poor hydration has been shown to impair aerobic exercise performance.[42] To ensure hydration before exercise, exercisers should minimize thirst by drinking generous amounts of fluid in the 24 hours

FIGURE 13.24
Recommended fluid intake
To maintain adequate hydration during extended exercise, it is important to carry water with you. Hydration packs such as the one worn by this runner can be used for biking, hiking, and jogging.

Universal Images Group/SuperStock

Before Exercise
• Begin exercise well hydrated by consuming generous amounts of fluid in the 24 hours before exercise.
• Consume about 2 cups of fluid at least four hours before exercise.
During Exercise
• Drink to satisfy thirst, or consume 6 to 12 oz of fluid every 15 to 20 minutes
• For exercise lasting 60 minutes or less, plain water is the only fluid needed, but beverages containing carbohydrate and electrolytes will not hurt performance.
• For exercise lasting longer than 60 minutes, consuming a fluid containing about 6 to 8% carbohydrate may improve endurance.
• For exercise lasting longer than 60 minutes, a fluid containing electrolytes can increase fluid intake by stimulating thirst and increasing absorption.
After Exercise
• Begin fluid replacement immediately after exercise.
• Consume 16 to 24 oz of fluid for each pound of weight lost.

before the exercise session and about 2 cups of fluid at least four hours before exercise.[38] During exercise, whether casual or competitive, exercisers are advised to drink enough water to prevent weight loss in excess of 2% of body weight.[25] New evidence suggests that in most situations, drinking according to thirst throughout exercise will preserve extracellular fluid homeostasis and maximize endurance.[42] In situations where the thirst sensation may be unreliable, drinking 6 to 12 oz of fluid every 15 to 20 minutes beginning at the start of exercise should maintain adequate hydration (Figure 13.24). To restore lost water after exercise, each pound of weight lost should be replaced with 16 to 24 oz (2 to 3 cups) of fluid.

What Should You Drink During Short Workouts? For exercise lasting an hour or less, water is the only fluid needed. For a 20-minute jog, 40 minutes at the gym, or a brisk walk through the park, sports drinks offer no advantage over a water bottle filled at the drinking fountain. Sports drinks will not hurt your performance in a short workout, but they may be counterproductive if the goal of exercise is weight loss. A typical sports drink contains about 50 kcal/cup, so drinking a 16-oz bottle at the gym will replace about half of the 200 kcal expended during your 40-minute ride on the stationary bicycle.

What Should You Drink During Long Workouts? For exercise lasting more than 60 minutes, beverages containing a small amount of carbohydrate and electrolytes are recommended. Consuming carbohydrate in a beverage helps to maintain blood glucose levels, thus providing a source of glucose for the muscle and delaying fatigue. The right proportion of carbohydrate to water is important. If the concentration of carbohydrate is too low, it will not help performance; if it is too high, it will delay stomach emptying (see **Debate: Energy Drinks for Athletic Performance?**).

Beverages containing 15 to 20 g of carbohydrate per cup (6 to 8%) are best. This is the amount of carbohydrate found in popular sports beverages such as Gatorade and PowerAde. Beverages containing larger amounts of carbohydrate, such as fruit juices, energy drinks, and soft drinks, are not recommended unless they are diluted with an equal volume of water. Water and carbohydrate trapped in the stomach do not benefit the athlete. Flavored beverages are also advantageous because they tempt athletes to drink more, helping to ensure adequate hydration.

The amount of sodium lost during exercise lasting less than three to four hours is small. Even though there may not be a physiological need to replace sodium, a beverage containing 500 to 700 mg of sodium per liter (around 150 mg/cup) is recommended for exercise lasting more than an hour.[25] This is because the sodium enhances palatability and the drive to drink, so it may cause an increase in fluid intake. The presence of small amounts of sodium and glucose also slightly increases the rate of water absorption. A sodium-containing beverage will also help prevent hyponatremia in athletes who overhydrate and in those participating in endurance events, such as ultramarathons or Ironman Triathlons, in which significant amounts of sodium may be lost in sweat.

DEBATE

Energy Drinks for Athletic Performance?

Tony Cenicola/Redux Pictures

The popularity of energy drinks with names like Monster, Red Bull, and Full Throttle has soared during the past decade. They promise to keep you alert to study, work, drive, party all night, and perhaps excel at your next athletic competition. They are sold alongside sports drinks, and manufacturers of these beverages often sponsor athletes and athletic events. Should they be used as ergogenic (performance-enhancing) aids? Is drinking them a safe way to improve your game?

The main ingredients in these drinks are sugar and caffeine. Sugar is an important fuel for exercise. A traditional sports drink, like Gatorade, contains about 28 g of sugar in 16 oz; a typical energy drink provides twice this much (55 to 60 g, or about 14 tsp). Since glucose fuels activity, the additional sugar could provide the extra energy needed for prolonged exercise. But more may not always be better during activity. Providing more sugar does not increase the rate at which it is absorbed, so energy drinks don't get any more glucose to the muscles than sports drinks do. The unabsorbed sugar in the stomach and intestines can cause GI distress and slow fluid absorption.

The caffeine content of energy drinks ranges from about 50 to 500 mg per can or bottle. Caffeine is an effective ergogenic aid that enhances endurance when consumed in moderate doses (3 to 6 mg/kg body weight or about 200 to 400 mg for a 150-lb person).[43] So, the caffeine in energy drinks is likely responsible for the ergogenic effects of these beverages.[44] However, too much caffeine, referred to as *caffeine intoxication*, causes nervousness, anxiety, restlessness, insomnia, gastrointestinal upset, tremors, increased blood pressure, and rapid heartbeat. This is a particular concern in young athletes because their lower body weight means that the energy drink supplies more caffeine per kilogram than in an adult. A number of cases of caffeine-associated cardiac arrest, seizure, and death have occurred after consumption of energy drinks.[45–47] The timing of energy drink consumption may be important; caffeine ingested in the evening has less of an ergogenic effect and more side effects.[48] If energy drinks are used as a fluid replacement beverage during exercise, particularly in a hot environment, enough caffeine may be consumed to alter fluid and mineral balance and increase core temperature.[44] The FDA limits the amount of caffeine in soft drinks to 0.02% (about 71 mg in 12 oz), but energy drinks are considered dietary supplements, so the caffeine content is not regulated.

Energy drinks often also contain other ingredients that promise to improve performance, such as B vitamins, taurine, guarana, and ginseng. B vitamins are needed to produce ATP, so they are marketed to enhance energy production from sugar. But unless you are deficient in these vitamins, getting them from an energy drink will not enhance your ATP production. Taurine is an amino acid that may reduce the amount of muscle damage and improve exercise performance and capacity, but not all research supports these claims.[47] Guarana is an herbal ingredient that contains caffeine as well as small amounts of the stimulants theobromine and theophylline. The extra caffeine from guarana (not included in the caffeine listed for these beverages) may contribute to caffeine intoxication. Ginseng is also claimed to have performance-enhancing effects, but these effects have not been demonstrated scientifically.[46,49] Even if these ingredients are ergogenic, the amounts contained in energy drinks may be too small to have an effect, and the safety of consuming them in combination with caffeine prior to or during exercise has yet to be established.[46]

So should you down an energy drink before your next competition? They do provide a caffeine boost, but is it so much caffeine that you risk dehydration, high blood pressure, and heart problems? Energy drinks provide sugar to fuel activity, but will they upset your stomach? What about the herbal ingredients—do they offer a benefit you are looking for?

THINK CRITICALLY: Sugar-free energy drinks are now available. How would this affect their usefulness as an ergogenic aid?

13.6 Food and Drink to Maximize Performance

LEARNING OBJECTIVES

- Discuss the advantages and disadvantages of carbohydrate loading.
- Explain the recommendations for food and drink during extended exercise.
- Plan precompetition and postcompetition meals for a marathon runner.

For most of us, a trip to the gym requires no special nutritional planning, but for competitive athletes, when they eat and what they eat before, during, and after competition is as important as a balanced overall diet. Food eaten at these times may give or take away the extra seconds that can mean victory or defeat.

Maximizing Glycogen Stores

Glycogen provides a source of stored glucose. Larger glycogen stores allow exercise to continue for longer periods. Glycogen stores and hence endurance are increased by increasing carbohydrate intake (Figure 13.25).

glycogen supercompensation or **carbohydrate loading**
A regimen designed to maximize muscle glycogen stores before an athletic event.

Serious endurance athletes who want to increase their glycogen stores substantially before a competition may choose to follow a dietary regimen referred to as **glycogen supercompensation** or **carbohydrate loading**. This involves resting for one to three days before competition while consuming a very-high-carbohydrate diet.[51] The diet should provide 10 to 12 g of carbohydrate per kilogram of body weight per day. For a 150-lb person, this is equivalent to about 700 g of carbohydrate per day. Having a stack of pancakes with syrup and a glass of milk or a plate of pasta with garlic bread and a glass of juice provides more than 200 g of carbohydrate. A number of commercial high-carbohydrate beverages, containing 50 to 60 g of carbohydrate in 8 fluid ounces, are available to help athletes consume the amount of carbohydrate recommended to maximize glycogen stores. These should not be confused with sports drinks designed to be consumed during competition, which contain only about 15 to 20 g of carbohydrate in 8 fluid ounces. Trained athletes who follow a carbohydrate-loading regimen can double their muscle glycogen content.[51]

Although glycogen supercompensation is beneficial to endurance athletes, it will provide no benefit and even has some disadvantages for people exercising for periods of less than 90 minutes. For every gram of glycogen in the muscle, 3 g of water are also deposited. This water can produce a 2- to 7-lb weight gain and may cause some muscle stiffness. The extra weight is a disadvantage for those competing in events of short duration, but because the water is released as glycogen is used, this can be an advantage when exercising in hot weather.

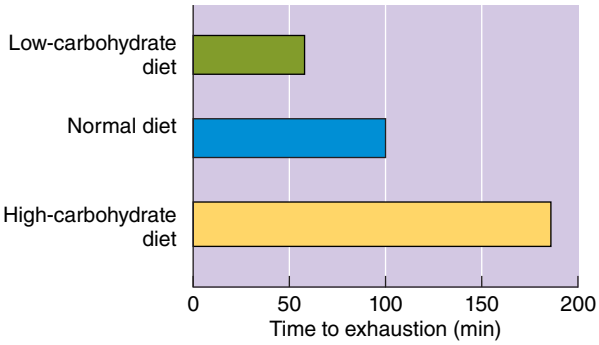


FIGURE 13.25 Effect of carbohydrate consumption on endurance
The amount of carbohydrate consumed in the diet affects the level of muscle glycogen and hence an athlete's endurance. This graph shows endurance capacity during cycling exercise after three days of a very-low-carbohydrate diet (less than 5% of energy from carbohydrate), a normal diet (about 55% carbohydrate), and a high-carbohydrate diet (82% carbohydrate).[50]

What to Eat Before Exercise

An athlete who is hungry will not perform at his or her best, but the wrong meal can hinder performance more than the right one can enhance it. The size, composition, and timing of the pre-exercise meal are all important. The goal of meals eaten before exercise is to maximize glycogen stores and provide adequate hydration while minimizing hunger and any undigested food in the stomach that can lead to gastric distress.

Ideally, a pre-exercise meal should provide enough fluid to maintain hydration and be high in carbohydrate (60 to 70% of calories). This will help to maintain blood glucose and maximize glycogen stores. Muscle glycogen is only depleted by exercise, but liver glycogen is used to supply blood glucose, so it is depleted even during rest if no food is ingested. So, first thing in the morning, liver glycogen stores have been reduced by the overnight fast. A high-carbohydrate meal eaten three to four hours before the event will fill liver glycogen stores. In addition to being high in carbohydrate, the pre-exercise meal should be moderate in protein (10 to 20%)

and low in fat (10 to 25%) and fiber to minimize gastrointestinal distress and bloating during competition.[38] A cup of pasta with marinara sauce and a slice of bread, or a turkey sandwich and a cup of juice, are good choices. Spicy foods that could cause heartburn, and large amounts of simple sugars that could cause diarrhea, should be avoided unless the athlete is accustomed to eating these foods.

In addition to providing nutritional clout, a meal that includes "lucky" foods may provide some athletes with an added psychological advantage. Some athletes find that in addition to a precompetition meal, a small high-carbohydrate snack or beverage consumed shortly before an event may enhance endurance. Because foods affect people differently, athletes should test the effect of these meals and snacks during training, not during competition.

What to Eat During Exercise

Regardless of the type or duration of exercise, maintaining adequate fluid intake is important while exercising (see Figure 13.24). For exercise that lasts more than an hour, consuming about 30 to 60 g of carbohydrate per hour (the amount in a banana or an energy bar) can enhance endurance.[25] Consuming carbohydrate during exercise is particularly important for athletes who exercise in the morning, when liver glycogen levels are low.

Carbohydrate intake should begin shortly after exercise commences and regular amounts should be consumed every 15 to 20 minutes during exercise. The carbohydrate should provide glucose, glucose polymers (chains of glucose molecules), or a combination of glucose and fructose.[25] Fructose alone is not as effective and may cause diarrhea. Some athletes may prefer to obtain this carbohydrate from a sports drink, while others prefer a high-carbohydrate snack or energy gel consumed with water (see **Off the Label: What Are You Getting from That Sports Bar?**). Energy gels consist of a thick carbohydrate syrup packaged in a palm-size packet. The contents can be sucked out of the packet, providing about 20 g of carbohydrate.

During exercise, sodium and other minerals are lost in sweat. Although the amounts lost during exercise lasting less than three hours are usually not enough to affect health or performance, a snack or beverage containing sodium is recommended for exercise lasting one hour or more. As discussed earlier, sodium enhances the palatability of beverages and increases the drive to drink, so even if sodium losses are small, consuming it during exercise may cause an increase in fluid intake.

What to Eat After Exercise

When exercise ends, the body must shift from the catabolic state of breaking down glycogen, triglycerides, and muscle proteins for fuel to the anabolic state of restoring muscle and liver glycogen, depositing lipids, and synthesizing muscle proteins. The goal for meals after exercise is to replenish fluid, electrolyte, and glycogen losses and to provide amino acids for muscle protein synthesis and repair. For example, a mixed meal such as pancakes and a glass of milk consumed soon after a strenuous competition or training session will help the athlete prepare for the next exercise session.

The first priority for all exercisers is to replace fluid losses; 16 to 24 oz should be consumed for every pound lost. Including sodium in the beverage helps recovery by decreasing urinary water losses.[38] For serious athletes, it may also be important to replenish glycogen stores rapidly. To maximize glycogen replacement, a high-carbohydrate snack or drink should be consumed within 30 minutes of completion of the competition and again every two hours for six hours after the event.[25] Ideally, the snacks or drinks should provide about 1.0 to 1.5 g of carbohydrate per kilogram of body weight, which is about 70 to 100 g of carbohydrate for a 154-lb (70-kg) person—the equivalent of 2 cups of pasta or 2 cups of low-fat chocolate milk. Consuming foods such as these that contain both carbohydrate and protein enhances glycogen synthesis even more than does consuming carbohydrate alone.[52,53] Including protein with carbohydrate in postexercise meals also stimulates muscle protein synthesis and provides the amino acids needed for muscle protein synthesis and repair.[54]

The glycogen-restoring regimen just described can replenish muscle and liver glycogen within 24 hours of an athletic event and is critical for athletes who must perform again the following day. Athletes not competing again the next day can replenish their glycogen stores more slowly by consuming high-carbohydrate foods for the next day or so. A diet providing about 65% of calories from carbohydrate, or about 400 g of carbohydrate in a 2500-kcal diet, should provide sufficient carbohydrate during the recovery period.[25]

OFF THE LABEL

What Are You Getting from That Sports Bar?

© iStockphoto

Looking for a convenient snack that can give you an energy boost during your bike ride or day of cross-country skiing? A sports bar may be the answer, but which should you choose? There are hundreds of varieties. Some are high in protein and low in carbohydrate; others are high in carbohydrate and low in fat; and some claim to have just the right balance of everything. They promise to optimize performance, build lean muscle, reduce body fat, increase strength, and speed recovery.

Carbohydrate is the fuel that becomes limiting during prolonged exercise, so if you want to have the energy to keep pedaling or skiing, choose high-carbohydrate bars, called energy or endurance bars. They have the carbohydrate needed to prevent hunger and maintain blood glucose during extended sports activities. Use the label to check out the amount of carbohydrate, fat, protein, and energy in different bars. A bar that provides about 45 g of carbohydrate (70% of calories) will help maintain your blood glucose level during exercise. Watch the fat and protein content; in 300 kcal you want no more than about 8 g of fat and 16 g of protein. Bars higher in fat or protein or lower in carbohydrate will not give you the blood glucose boost that you need to continue exercising.

Nutrition Facts

Serving Size 1 bar (2 oz.) (57g)

Amount Per Serving	
Calories 271	Calories from Fat 122
	% Daily Value*
Total Fat 14g	**21%**
Saturated Fat 5g	**26%**
Trans Fat 0g	
Cholesterol 5mg	**2%**
Sodium 140mg	**6%**
Total Carbohydrates 35g	**12%**
Dietary Fiber 1g	**5%**
Sugars 30g	
Protein 4g	

Vitamin A 2% • Vitamin C 0%
Calcium 5% • Iron 2%

*Based on a 2,000 calorie diet

Andy Washnik

Nutrition Facts

Serving Size 1 bar (65g)

Calories 230
Calories from Fat 20
Calories from Sat Fat 5

*Percent Daily Values (DV) are based on a 2,000 calorie diet.

Amount/Serving	% DV*	Amount/Serving	% DV*
Total Fat 2g	**3%**	**Total Carb** 45g	**15%**
Saturated Fat 0.5g	**3%**	Dietary Fiber 3g	**12%**
Trans Fat 0g		Sugars 14g	
Cholesterol 0mg	**0%**	Other Carb 28g	
Sodium 90mg	**4%**		
Potassium 145mg	**4%**	**Protein** 10g	

Vitamin A 0% • Vitamin C 100% • Calcium 30% • Iron 35% • Vitamin E 100%
Thiamin 100% • Riboflavin 100% • Niacin 100% • Vitamin B_6 100%
Folate 100% • Vitamin B_{12} 100% • Biotin 100% • Pantothenic Acid 100%
Phosphorus 35% • Magnesium 35% • Zinc 35% • Copper 35% • Chromium 20%

George Semple

Is a sports bar any better for you than a candy bar? A look at the labels shows that there is a difference (see figures). Typically, sports bars are lower in fat, higher in fiber, and contain more vitamins and minerals than candy bars. Many contain vitamin C, vitamin E, calcium, iron, magnesium, copper, zinc, and a host of B vitamins. All the added nutrients will appear in the ingredient list. The % Daily Value for calcium, iron, and vitamins A and C are required on current Nutrition Facts labels and % Daily Values for other vitamins and minerals may be included voluntarily.

So, should you be packing a sports bar on your next outing? It won't take the place of the whole grains, fresh vegetables and fruits, low-fat dairy products, and lean protein sources that make up a healthy diet. But, if having a compact, individually wrapped bar that can travel with you means the difference between consuming this snack or no food at all, sports bars can be beneficial. They may also provide a psychological edge if you believe they will enhance your performance.

If you choose to use these bars, wash them down with plenty of water. They don't provide fluid—an essential during any activity. Also remember that one sports bar provides around 200 to 300 kcal. Even though they are eaten to support activity, they still add to your overall energy intake and can contribute to weight gain if consumed in excess.

THINK CRITICALLY: Suggest a snack that provides about the same amount of carbohydrate and calories as an energy bar, but is less expensive.

Most people do not need a special glycogen replacement strategy to ensure glycogen stores are full by their next gym visit. Eating a typical diet that provides about 55% of calories as carbohydrate will quickly replace the glycogen used during a 30- to 60-minute workout at the gym.

13.7 Ergogenic Aids: Do Supplements Enhance Athletic Performance?

LEARNING OBJECTIVES

- Assess the health risks associated with anabolic steroids.
- Explain how supplements might enhance performance in short, intense activities.
- Describe one way in which a supplement might improve endurance.

Citius, altius, fortius—faster, higher, stronger—the Olympic motto. For as long as there have been competitions, athletes have yearned for something—anything—that would give them the competitive edge. Anything designed to enhance performance can be considered an **ergogenic aid**: Running shoes are mechanical aids; psychotherapy is a psychological aid; drugs are pharmacological aids. Many dietary supplements are also used as ergogenic aids. Although these supplements are often expensive and most have not been shown to improve performance, athletes are vulnerable to their enticements. When considering the use of an ergogenic supplement, an athlete should first weigh the health risks against potential benefits: Dietary supplements do not have to be proven safe or effective before they can be sold (see Chapter 2 and Focus on Dietary Supplements, as well as Table 13.3). The following sections discuss some of the more popular products. Others are reviewed in Table 13.4.

ergogenic aid Anything designed to increase work or improve performance.

Vitamin and Mineral Supplements

Many of the promises made to athletes about the benefits of vitamin and mineral supplements are extrapolated from their biochemical functions. For example, B-vitamin supplements are promoted to enhance ATP production because of the roles B vitamins play in muscle energy metabolism. Vitamins B_6, B_{12}, and folic acid are promoted for aerobic exercise because they are involved in the transport of oxygen to exercising muscles. These vitamins are indeed needed for energy metabolism, and a deficiency of one or more of these can interfere with ATP production and impair athletic performance; however, providing more than the recommended amount does not deliver more oxygen to the muscle, cause more ATP to be produced, or enhance athletic performance.

TABLE 13.3 Evaluating the Benefits and Risks of Ergogenic Supplements

Does the supplement meet your needs?
• Does the product contain the nutrient or other ingredient you are looking for?
• Has it been shown to provide the benefits you want?
Are the ingredients safe for you?
• Does it contain any ingredients that have been shown to be toxic to someone like you?
• Do you have a medical condition that would make it dangerous to take this product?
• Are you taking prescription medication that might interact with the supplement?
Is the dose safe?
• Does it contain potentially toxic levels of any nutrient? Check the % Daily Value for any nutrients that exceed 100%. If they do, do they exceed the UL?
• Take the dose recommended on the package. More isn't always better and may cause side effects.
How much does it cost?
• More expensive is not always better.
• Compare costs and ingredients before you buy.

TABLE 13.4 Claims, Benefits, and Risks of Popular Ergogenic Aids

Ergogenic aid	Promoter claims	Proven benefits	Potential risks
Arginine, ornithine, and lysine	Causes the release of growth hormone, which stimulates muscle development and decreases body fat.	No increase in lean body mass observed with supplementation.	Reduced absorption of other amino acids. Diarrhea at high doses.
β-Alanine	Increases strength, power, and endurance during high-intensity exercise.	Increases muscle carnosine, which prevents changes in muscle acidity. Delays fatigue and increases power output during short, intense activity.	Safety has not been adequately established.
Bicarbonate (sodium bicarbonate, baking soda)	Helps buffer lactic acid produced during exercise and delays fatigue.	Increases blood pH and may enhance performance during intense anaerobic activities.	Causes bloating, diarrhea, and high blood pH.
Branched-chain amino acids (leucine, isoleucine, and valine)	Improve endurance and prevent fatigue.	Evidence of an effect is inconsistent.	No toxicity reported.
Caffeine	Increases the release of fatty acids from adipose tissue, increases alertness, spares glycogen, and enhances endurance.	Increases endurance.	Nervousness, anxiety, insomnia, digestive discomfort, abnormal heartbeat.
Carnitine	Enhances the utilization of fatty acids and spares glycogen.	No increase in fatty acid utilization or improvement in exercise performance found.	D,L-Carnitine and D-carnitine forms can be toxic.
Chromium (chromium picolinate)	Increases lean body mass, decreases body fat, and delays fatigue.	No effect on protein or lipid metabolism unless a chromium deficiency exists.	No toxicity reported in humans.
Coenzyme Q10	Increases mitochondrial ATP production, acts as an antioxidant, and may combat fatigue.	No effect on exercise performance observed.	No toxicity reported.
Creatine (creatine monohydrate)	Increases ATP production and speeds recovery after high-intensity exercise.	Increases muscle creatine and creatine phosphate synthesis after exercise. Enhances strength, performance, and recovery from high-intensity exercise. Increases muscle mass.	No toxicity reported.
DHEA (dehydroepiandrosterone)	Builds muscles, burns fat, and delays chronic diseases associated with aging.	No proven benefits.	Acne, oily skin, facial hair, voice deepening, hair loss, mood changes, liver damage, and stimulation of existing cancers.
Glutamine	Increases muscle glycogen deposition following intense exercise, enhances immune function, and prevents the adverse effects of overtraining.	Little evidence that glutamine increases immune function, prevents the symptoms of overtraining, or increases glycogen synthesis.	No evidence of toxicity.
Glycerol	Improves hydration and endurance.	Evidence of an effect is equivocal.	May cause cellular dehydration, nausea, vomiting, diarrhea.
HMB (β-hydroxy-β-methylbutyrate)	Increases ability to build muscle and burn fat in response to exercise.	Some evidence of an increase in lean body mass and strength.	No toxicity in animals, but little information in humans.
Medium-chain triglycerides (MCTs)	Absorbed and metabolized rapidly to provide energy for activity without promoting fat deposition.	Provide fuel for aerobic metabolism. There is some evidence that they promote weight loss but they have not been found to improve athletic performance in humans.	None known.
Vanadium (vanadyl sulfate)	Aids insulin action and allows more rapid and intense muscle pumping for body builders.	No evidence to support a benefit for body builders.	Reduces insulin production.

Supplements of vitamin E, vitamin C, β-carotene, and selenium are promoted to athletes because of their antioxidant functions. As discussed earlier, exercise increases oxidative processes and therefore increases the production of free radicals, which cause cellular damage and have been associated with fatigue during exercise. It has been suggested that antioxidant supplements reduce the levels of free radicals and hence delay fatigue. However, this effect has not been supported by research, and supplementation of antioxidant nutrients may actually have a detrimental effect on training.[55] The best way to ensure adequate antioxidant protection is to consume a diet that includes plenty of whole grains, fruits, and vegetables, all of which are rich in antioxidant nutrients as well as antioxidant phytochemicals (see Chapter 12, *Debate: Antioxidant Supplements: Helpful or Harmful?*).

Supplements of chromium, vanadium, selenium, zinc, and iron are marketed to strengthen muscles or enhance endurance. As with vitamin supplements, many of the claims made about these minerals are based on their physiological functions. And as with vitamins, there is little evidence that consuming more than the recommended amount provides any benefits.[56]

Chromium supplements, as chromium picolinate, claim to increase lean body mass and decrease body fat. Chromium is needed for insulin action and insulin promotes protein synthesis. Therefore, adequate chromium status is likely to be important for lean tissue synthesis. The picolinate form is typically used because it is believed to be absorbed better than other forms of chromium. However, studies in humans have not consistently demonstrated an effect of supplemental chromium picolinate on muscle strength, body composition, body weight, or other aspects of health.[57]

Vanadium, usually as vanadyl sulfate, is another mineral marketed for its ability to promote the action of insulin. Vanadium supplements promise to increase lean body mass, but there is no evidence that they have an anabolic effect, and toxicity is a concern.[58]

Selenium is marketed for its antioxidant properties and zinc for its role in protein synthesis and tissue repair, but neither of these supplements has been found to improve athletic performance in individuals with adequate mineral status. Iron is also marketed as an ergogenic mineral because it is needed for hemoglobin synthesis. If an iron deficiency exists, as it frequently does in female athletes, supplements can be of benefit.

Supplements to Build Muscle

Hundreds of millions of dollars are spent each year on supplements to build muscle size, strength, and power. The most popular are protein supplements, but supplements of certain amino acids, as well as muscle-building hormones with dangerous side effects, are also used.

Do Protein Supplements Help Build Muscle? Protein supplements—from powders you mix in your beverage to bars you put in your backpack—are marketed to athletes with the promise of enhancing muscle growth or improving performance. Muscles enlarge in response to exercise. Resistance training stimulates muscle protein synthesis. Adequate protein is necessary for protein synthesis to occur. Consuming high-quality proteins such as milk and soy proteins after intense resistance training has been found to maximize muscle growth stimulated by exercise.[59] This effect can be obtained by consuming protein from a protein supplement or a glass of chocolate milk. However, overall protein intake in excess of recommended amounts either as food or supplements does not increase muscle growth or strength.[56] If an athlete's diet provides enough energy, it usually provides enough protein without adding a supplement (see *Critical Thinking: Getting Enough Protein?*).

Growth Hormone and Growth Hormone Releasers Growth hormone, although banned by the World Anti-Doping Agency, is appealing to athletes because it increases muscle protein synthesis. Despite this physiological effect, however, it has not been shown to enhance muscle strength, power, or aerobic exercise capacity, but there is evidence that it improves anaerobic exercise capacity.[60] Prolonged use of growth hormone can cause heart dysfunction, high blood pressure, and excessive growth of some body parts, such as hands, feet, and facial features.

Supplements of the amino acids arginine, ornithine, and lysine are marketed with the promise that they will stimulate the release of growth hormone, which increases the growth of muscles. Large doses of these amino acids have been shown to stimulate the release of growth hormone, and some studies have found that supplements of these amino acids cause growth

THINK CRITICALLY

Why does anabolic steroid use promote muscle development while causing the testes to shrink?

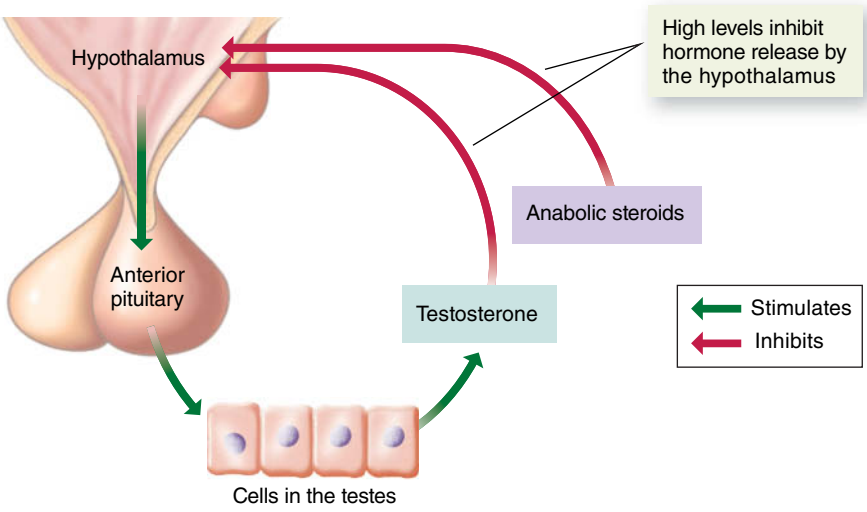


FIGURE 13.26 Anabolic steroids
When testosterone levels are low, the hypothalamus releases a hormone that stimulates the anterior pituitary to secrete a hormone that increases the production of testosterone by the testes. High levels of either natural or synthetic testosterone inhibit the release of the stimulatory hormone from the hypothalamus, shutting down the synthesis of natural testosterone.

hormone levels to increase more than they do from exercise alone, but the effect this has on exercise performance needs further investigation.[61–63]

Anabolic Steroids and Steroid Precursors Anabolic steroids are synthetic versions of the human steroid hormone testosterone. Natural testosterone stimulates and maintains the male sexual organs and promotes the development of bones and muscles and the growth of skin and hair. The synthetic testosterone in anabolic steroids has a greater effect on muscle, bone, skin, and hair than it does on sexual organs. When taken in conjunction with exercise and an adequate diet, anabolic steroids cause increases in muscle size and strength. However, they have extremely dangerous side effects. Side effects occur because these drugs make the body think natural testosterone is being produced, so that the body shuts down its own testosterone production (Figure 13.26). Without natural testosterone, the sexual organs are not maintained; this leads to shrinkage of the testicles and a decrease in sperm production.[64]

LIFE CYCLE

In adolescents, the use of anabolic steroids causes cessation of bone growth and stunted height. Anabolic steroid use may also cause oily skin and acne, water retention in the tissues, yellowing of the eyes and skin, coronary artery disease, liver disease, and sometimes death. Users may experience psychological and behavioral side effects such as violent outbursts and depression, possibly leading to suicide.[63]

The possession of anabolic steroids without a prescription is illegal. This regulation also applies to steroid precursors, which are compounds that can be converted into steroid hormones in the body. The best known of these is androstenedione, often referred to as "andro." It was launched into public prominence when professional baseball player Mark McGwire announced his use of it during the 1998 major league baseball season, when he hit 70 home runs, breaking the league's single-season home-run record. Contrary to marketing claims, the use of andro or other steroid precursors has not been found to increase testosterone levels or produce any ergogenic effects, and they may cause some of the same side effects as anabolic steroids.[65]

β-Hydroxy-β-Methylbutyrate β-Hydroxy-β-methylbutyrate, known as HMB, is a metabolite of the branched-chain amino acid leucine that is promoted as a muscle builder. Supplements of HMB, claim to increase strength and muscle growth and improve muscle recovery; however, the outcome of research studies has been variable. Overall, studies have found a small increase in strength in previously untrained men, but the effects in trained weightlifters are trivial, as is the effect of HMB on body composition.[66]

Supplements to Enhance Performance in Short, Intense Activities

A number of supplements are marketed to athletes who seek to improve performance in sports that depend on quick bursts of intense activity. Some have benefits because they help the body cope with the metabolic stress of very intense activities.

Creatine Supplements Creatine is a nitrogen-containing compound found primarily in muscle, where it is used to make creatine phosphate, a source of energy for short-term exercise. It can be synthesized in the liver, kidneys, and pancreas from the amino acids arginine, glycine, and methionine. It is also consumed in the diet in meat and milk. The more creatine in the diet, the greater the amount of creatine stored in muscle. Creatine supplements increase levels of both creatine and creatine phosphate in muscle (Figure 13.27). Higher levels of these provide muscles with more quick energy for short-term maximal exercise. Creatine supplementation when combined with strength training has been shown to increase strength, power, and muscle mass more than strength training alone. Creatine supplements have the greatest benefit for short-duration high-intensity intermittent exercise such as sprinting and weightlifting.[67]

Creatine supplementation is currently considered safe, but the long-term safety has not been established in populations such as the young and the elderly.[67] High-dose creatine supplementation (> 3 to 5 g/day) is not advised for those with preexisting kidney disease or a disorder such as hypertension or diabetes that increases the risk of kidney dysfunction.[68]

β-Alanine β-Alanine supplements are marketed to increase strength, power, and endurance during high-intensity exercise. β-Alanine is a nonessential amino acid that is used in the muscle to synthesize a compound called carnosine. Carnosine is a buffer that prevents changes in acidity within the muscle. During high-intensity exercise, lactic acid is produced, causing muscle pH to decline. The increase in acidity is believed to interfere with muscle function and contribute to fatigue. Supplements of β-alanine increase muscle carnosine concentration, which is hypothesized to delay the onset of fatigue by preventing the decrease in muscle pH. Studies of β-alanine supplementation have found that supplements can delay fatigue and increase the ability to sustain muscle power output during high-intensity exercise lasting between one and four minutes.[69] The safety of β-alanine has not been adequately studied, so caution is recommended in using this supplement as an ergogenic aid.[70]

Bicarbonate Bicarbonate also acts as a buffer in the body. Supplementing it is thought to neutralize acid and thus delay fatigue and allow improved performance. Taking sodium bicarbonate, which is just baking soda from the kitchen cupboard, before exercise has been found to improve performance and delay exhaustion in sports, such as sprint cycling, that entail intense exercise lasting only one to seven minutes, and may also be useful for sports involving intermittent or sustained periods of high-intensity exercise.[71] Just because baking soda is an ingredient in your cookies does not mean that it is without risk. Many people experience abdominal cramps and diarrhea after taking sodium bicarbonate, and other possible side effects have not been carefully researched.

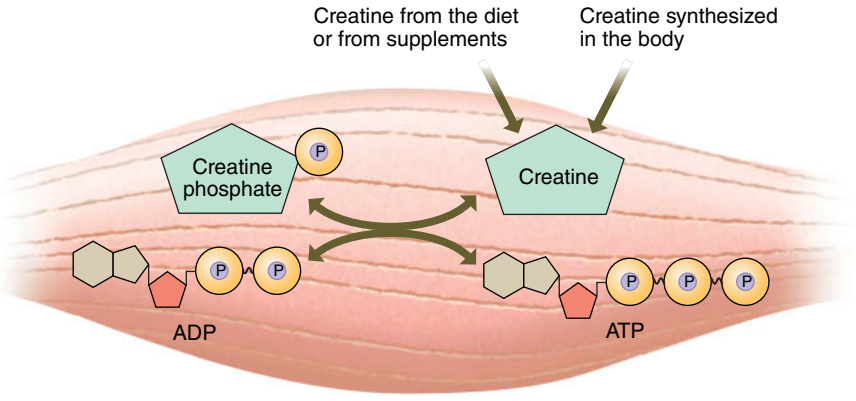


FIGURE 13.27 Creatine and creatine phosphate Creatine is consumed in the diet and made in the body. Increasing creatine consumption increases the amount of creatine and creatine phosphate stored in the muscle. During short bursts of intense activity, creatine phosphate can transfer a phosphate group to ADP, forming creatine and ATP that can be used for muscle contraction.

SCIENCE APPLIED

EPO: Lifesaver and Scandal

Since the 19th century, it has been known that people who live at high altitudes have "thicker" blood (that is, more red blood cells) than people who live at low altitudes, and that moving to a higher altitude can increase red blood cell production.[73] More red blood cells means the blood can carry more oxygen to support aerobic metabolism. Understanding how the thin air at high altitudes stimulates red blood cell production would have significant impact on the treatment of anemia and, interestingly enough, sports performance and sports scandal.

THE SCIENCE

In an attempt to identify the substance responsible for stimulating red blood cell production, French researchers in the early 20th century examined the effects of bloodletting on rabbits. When the blood taken from bled rabbits was given to unbled ones, red blood cell production increased in these animals, indicating the presence of the substance that stimulated red blood cell synthesis. Scientists ultimately called this hormone erythropoietin after erythropoiesis, the process of red blood cell formation.

Interest in erythropoietin increased in the 1950s, when the Cold War focused research priorities on ways to protect the human body from the effects of nuclear radiation, including anemia. In 1955, the Atomic Energy Commission awarded Dr. Eugene Goldwasser of the University of Chicago a grant to isolate and characterize erythropoietin. To find out where erythropoietin was produced, Dr. Goldwasser systematically removed the organs of laboratory rats. He concluded that the kidneys produced erythropoietin because blood withdrawal did not stimulate red blood synthesis when the kidneys were removed, but it did after removal of other organs. To isolate the compound, he needed large amounts. A breakthrough came in 1975, when Dr. Takaji Mijake of Japan's Kumamoto University arrived in Chicago and met Dr. Goldwasser with a vial containing the dried concentrate of 2550 L, or about 674 gallons, of urine he had collected from patients with aplastic anemia.[73] This anemia causes excess erythropoietin to be produced and excreted in the urine. Mijake, Goldwasser, and their colleagues were able to isolate 8 mg of human erythropoietin from this concentrate.[74] The 20-year quest to isolate the hormone had come to an end.

THE APPLICATION

In 1980, Dr. Goldwasser gave a sample of purified erythropoietin to a small, new California-based biotech company, which became known as Amgen. Scientists at Amgen went on to clone the gene that codes for erythropoietin and use it to produce the protein through genetic engineering. Amgen was interested in erythropoietin, which became known as EPO, because it believed the hormone could cure various types of anemia, including that which occurs in patients with kidney failure. When kidney function declines, natural erythropoietin is no longer produced, resulting in anemia (see figure). In clinical trials, administration of genetically engineered EPO was shown to correct anemia in dialysis patients.[75] This led to the approval of the first recombinant human erythropoietin product in 1989.

The usefulness of genetically engineered EPO did not stop with kidney patients. It is now used to treat HIV patients who have anemia associated with antiviral drug treatments, cancer patients who are suffering from anemia associated with chemotherapy, and to boost blood production in patients who wish to donate their own blood for use during surgery.

Athletes also became aware of the potential benefits of EPO. To increase aerobic capacity, athletes often train at high altitudes where low oxygen concentrations stimulate the production of red blood cells; upon returning to lower elevations, their blood then delivers more oxygen to their exercising muscles. Some athletes use oxygen deprivation tents to simulate the effect of high altitude. Yet these solutions are temporary. EPO provides a convenient, more lasting solution. Injections of EPO increase the total circulating red cell volume and therefore increase aerobic capacity and delay fatigue. Unfortunately, the benefits do not come without

Branched-Chain Amino Acids Supplements of the branched-chain amino acids (leucine, isoleucine, and valine) are promoted to improve athletic performance by reducing protein breakdown and increasing protein synthesis in skeletal muscle during recovery from strength exercise. Although studies examining branched-chain amino acid supplements have not found them to enhance performance, there is evidence that they may have some benefits in improving muscle recovery and preventing muscle soreness after intense exercise.[72]

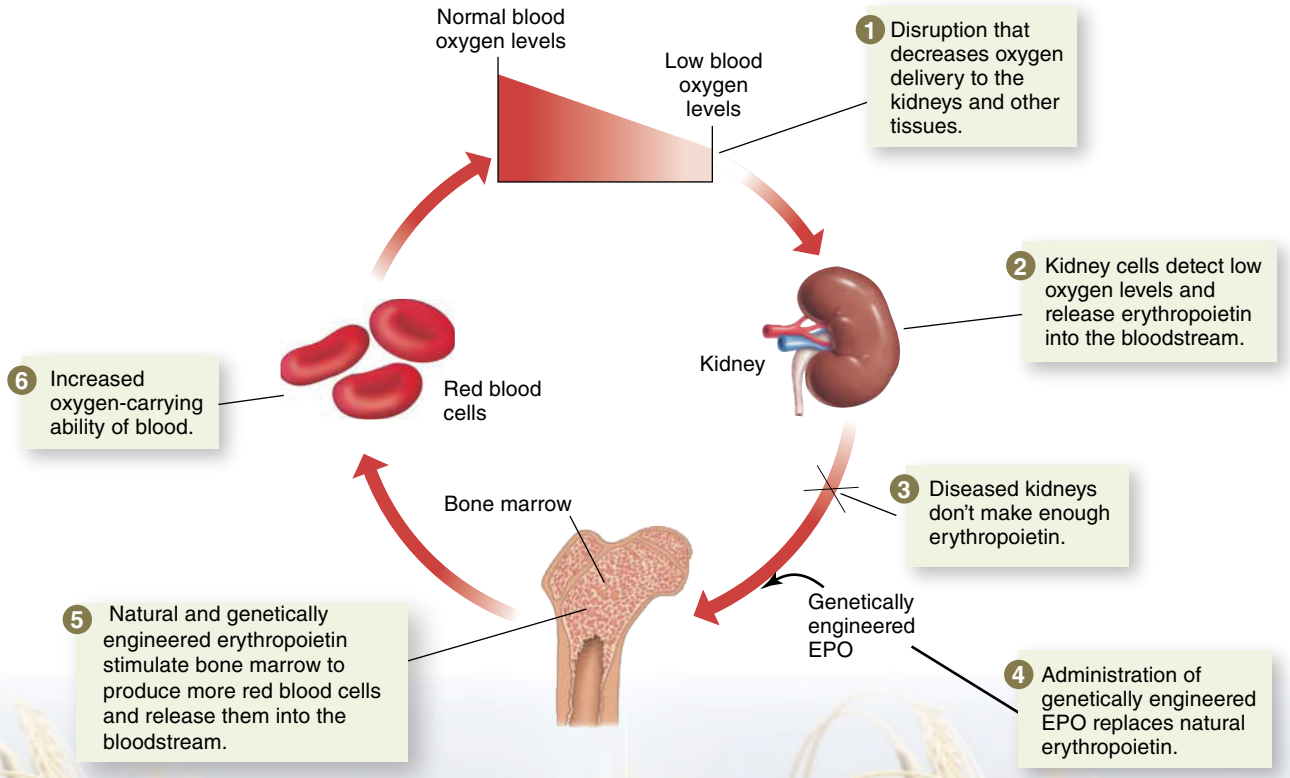
(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

risks. In the late 1980s, 18 young professional cyclists died from apparent unknown causes when erythropoietin was first introduced into the world of cycling, and since then many other deaths have been linked to its use. It was determined that EPO can endanger athletes because the high concentration of red blood cells can clog arteries and lead to stroke and heart attack. EPO can also cause sudden death by reducing heart rate, usually at night, and users can develop anti-erythropoietin antibodies, which may cause a reduction in the red cell mass.[76] The use of EPO by athletes has been banned since the early 1990s.

Today, EPO saves the lives of renal, cancer, and HIV patients, but has also led to scandal in the sports world as athletes are tempted by this drug that boosts their ability to produce ATP aerobically. Research now focuses not just on the clinical applications of EPO, but also on ways to detect the illegal use of EPO among athletes.



When availability of oxygen in the blood decreases, it stimulates the kidney to secrete erythropoietin, which acts at the bone marrow to increase red blood cell synthesis. In renal failure, the kidney is unable to produce erythropoietin, so red cell production declines, resulting in anemia. Administration of genetically engineered erythropoietin prevents or cures the anemia.

Supplements to Enhance Endurance

A primary performance concern for long-distance runners and cyclists is running out of glycogen. Glycogen is spared and endurance enhanced when aerobic metabolism predominates and fat is used as an energy source. A number of substances, including carnitine, medium-chain triglycerides, and caffeine, are taken to increase endurance by increasing the amount of fat available to the muscle cells. Athletes also use the banned hormone erythropoietin, known as EPO, to increase aerobic capacity (see **Science Applied: EPO: Lifesaver and Scandal**).

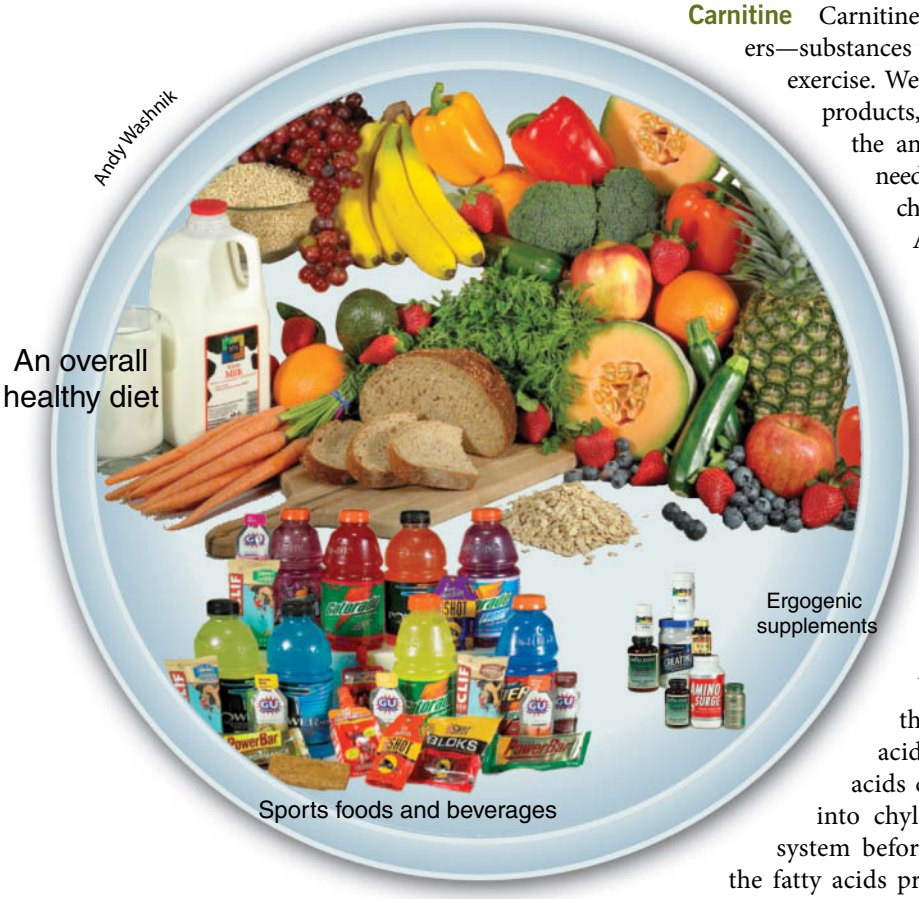


FIGURE 13.28 The impact of diet and supplements on exercise performance
This figure illustrates the relative importance of various nutrition strategies for exercise performance. Along with talent and hard work, eating a healthy overall diet provides the most significant benefit. Performance can be further improved by using appropriate foods and fluids to help refuel and rehydrate during workouts and events. Where do supplements fit in? Most of them don't, but specific types of athletes in certain events will receive an additional small benefit from a few select supplements.

Carnitine Carnitine supplements are marketed as fat burners—substances that increase the utilization of fat during exercise. We ingest carnitine in red meats and dairy products, and it is synthesized in the body from the amino acids lysine and methionine. It is needed to transport fatty acids into the mitochondria, where they are used to produce ATP by aerobic metabolism. Supplements promise to speed up the delivery of fatty acids to muscle mitochondria and therefore enhance the utilization of fat during exercise. Even when dietary carnitine is low, enough carnitine is made in the body to ensure efficient use of fatty acids. Carnitine supplements have not been shown to increase endurance.[77]

Medium-Chain Triglycerides Most of the fatty acids used by the muscle to generate ATP are delivered in the blood, so, theoretically, higher levels in the blood increase the availability of fatty acids as a fuel for exercise. Most of the fatty acids consumed in the diet are incorporated into chylomicrons, which enter the lymphatic system before they appear in the blood. However, the fatty acids provided by medium-chain triglycerides (MCTs) are only 8 to 10 carbons in length and are therefore soluble in water. They are absorbed directly into the blood without being incorporated into chylomicrons. In addition to being absorbed much more quickly, these fatty acids cross cell membranes more easily and can enter the mitochondria for oxidation without the help of carnitine. When MCTs are ingested, blood fatty acid levels increase. Despite this, research has not found that supplementation with MCT increases endurance, spares glycogen, or enhances performance.[78]

Caffeine Caffeine is a stimulant found in coffee, tea, energy drinks, and some soft drinks (see *Debate: Energy Drinks for Athletic Performance?*). Consuming 3 to 6 mg of caffeine per kilogram of body weight, an amount equivalent to about 2.5 cups of percolated coffee, up to an hour before exercising has been shown to improve performance for sustained endurance exercise as well as intermittent activity of prolonged duration as occurs in a team sport such as soccer.[43] Higher doses do not further enhance performance. Caffeine enhances performance both through its stimulatory effect on the central nervous system, which increases vigilance and alertness, and by increasing the release of fatty acids.[43,79] When fatty acids are used as a fuel source, less glycogen is used, and the onset of fatigue is delayed. Caffeine is a diuretic but does not cause significant dehydration during exercise. Athletes who are unaccustomed to caffeine respond better to it than do those who consume caffeine routinely, and in some athletes, it may impair performance by causing GI upset.

EPO Athletes also use the hormone erythropoietin, known as EPO, to enhance endurance. Natural erythropoietin is produced by the kidneys and stimulates cells in the bone marrow to differentiate into red blood cells (see *Science Applied: EPO: Lifesaver and Scandal*). EPO can enhance endurance by increasing the ability to transport oxygen to the muscles. It therefore increases aerobic capacity and spares glycogen. However, too much EPO can cause production of too many red blood cells, which can lead to excessive blood clotting, heart attacks, and strokes. EPO was banned for use by competitive athletes in 1990, after it was linked to the deaths of more than a dozen cyclists.

How Diet and Supplements Affect Performance

The foundation of superior athletic performance is talent, hard work, and a healthy diet. Supplements may garner most of the press when it comes to exercise performance, but their impact is very small compared to that of a healthy diet (Figure 13.28). A diet that supports an active lifestyle provides the right number of calories to keep weight in the desirable range; the proper balance of carbohydrate, protein, and fat to fuel activity and maintain tissues; plenty of water; and sufficient but not excessive amounts of essential vitamins and minerals. It is rich in whole grains, fruits and vegetables, high in fiber, moderate in fat and sodium and low in saturated fat, *trans* fat, and added sugars. Whether you are a couch potato or an Olympic hopeful, the recommendations of MyPlate and the Dietary Guidelines can help you choose a diet that provides the foundation for optimal performance.

OUTCOME

After reaching the rim of Crater Lake, Jason takes his time at the lunch stop, not only to enjoy the gorgeous vistas, but also to eat a good lunch and drink plenty of fluids. After refueling and rehydrating, Jason feels good for the rest of the day's ride. Jason ran into trouble because he didn't feel hungry, so he passed on the opportunity to pick up food and water. His friend knew to anticipate his needs by eating every hour or two and drinking often, even if he didn't feel hungry or thirsty, because it takes time for dietary carbohydrate to boost blood glucose levels. By not eating, Jason had cut off the supply of glucose from his diet. On the uphill ride to Crater Lake, his body was forced to use stored glycogen faster, depleting his muscle and liver stores. His liver could not supply blood glucose fast enough to meet his needs. He was also mildly dehydrated, further contributing to his fatigue. The next day had more hard climbs, but Jason made sure his water bottle was filled, that he ate at every rest stop, and that he took additional snacks with him. **Jason and his friend completed the ride and are hoping to do a similar ride next year.**

SUMMARY

13.1 Nutrition, Physical Activity, and Health

- How fit an individual is depends on his or her cardiorespiratory endurance, muscle strength, muscle endurance, flexibility, and body composition. Regular aerobic exercise increases aerobic capacity and resistance exercise increases muscle strength.
- Regular physical activity can reduce the risk of chronic diseases such as obesity, heart disease, diabetes, osteoporosis, and certain types of cancer. Physical activity helps manage body weight by increasing energy expenditure and by increasing the proportion of body weight that is lean tissue. Exercise also improves sleep patterns and promotes well-being by improving mood, boosting self-esteem, and reducing depression and anxiety.

13.2 Physical Activity Recommendations

- The current physical activity recommendations suggest a minimum of 150 minutes per week of moderate-intensity aerobic activity. Greater benefits are obtained from exercising longer or at higher intensity. In addition to aerobic exercise, an exercise program should include muscle-strengthening exercise and exercises to promote flexibility, balance, and agility. Time spent in strength and flexibility training does not count toward the goal of 150 minutes of aerobic exercise per week.
- Exercise recommendations for children suggest a minimum of 60 minutes of activity per day, some of which is muscle strengthening and bone strengthening. Activities should be age appropriate.

- An exercise program should include activities that are enjoyable, convenient, and safe. Various combinations of exercise frequency, intensity, and duration can meet exercise goals. Rest is important to allow the body to recover and rebuild. In serious athletes, inadequate rest can lead to overtraining syndrome.

13.3 Exercise and Energy Metabolism

- During the first 10 to 15 seconds of exercise, ATP and creatine phosphate stored in the muscle provide energy to fuel activity. During the next two to three minutes, the amount of oxygen at the muscle remains limited, so ATP is generated by the anaerobic metabolism of glucose. After a few minutes, the delivery of oxygen at the muscle increases, and ATP can be generated by aerobic metabolism. Aerobic metabolism is more efficient than anaerobic metabolism and can utilize glucose, fatty acids, and amino acids as energy sources. The use of protein as an energy source increases when exercise continues for many hours.
- For short-term, high-intensity activity, ATP is generated primarily from the anaerobic metabolism of glucose from muscle glycogen stores. Exercise that relies on anaerobic metabolism depletes glycogen rapidly, resulting in fatigue. For lower-intensity exercise of longer duration, aerobic metabolism predominates, and both glucose and fatty acids are important fuel sources.
- Fitness training causes changes in the cardiovascular system and muscles that improve oxygen delivery and utilization and increase glycogen stores, allowing aerobic exercise to be sustained for longer periods at higher intensity.

13.4 Energy and Nutrient Needs for Physical Activity

- The amount of energy needed for activity depends on the intensity, duration, and frequency of the activity, as well as the characteristics of the exerciser. The EER is increased by increases in activity level. The desire for weight loss to improve performance can lead to unhealthy weight-loss practices and eating disorders. Female athletes who restrict food intake may develop the female athlete triad, a combination of low energy intake, abnormal hormone levels, and low bone density. A combination of adequate protein, resistance exercise, and increased energy intake can help promote an increase in weight and muscle mass.
- To maximize glycogen stores, optimize performance, and maintain and repair lean tissue, a diet providing about 60% of energy from carbohydrate, 20 to 25% of energy from fat, and 15 to 20% of energy from protein is recommended.
- Sufficient vitamins and minerals are needed to generate ATP from macronutrients, to maintain and repair tissues, and to transport oxygen and wastes to and from the cells. Most athletes who consume a varied diet that meets their energy needs also meet their vitamin and mineral needs. Those who restrict their food intake may be at risk for deficiencies. Increased iron needs and greater iron losses due to fitness training put athletes, particularly female athletes, at risk of iron deficiency. Athletes are also at risk of deficiencies of calcium and vitamin D.

13.5 Fluid Needs for Physical Activity

- Water is needed to ensure that the body can be cooled and that nutrients and oxygen can be delivered to body tissues. If water intake is inadequate, dehydration can lead to a decline in exercise performance and increase the risk of heat-related illness. The risk of dehydration is increased when environmental temperature and humidity are elevated.
- Exercising in hot weather can lead to heat-related illnesses, including heat cramps, heat exhaustion, and heat stroke.
- Drinking plain water during extended exercise increases the risk of hyponatremia, a low concentration of sodium in the blood.
- Adequate fluid intake before exercise ensures that athletes begin exercise well hydrated. Fluid intake during and after exercise must replace water lost in sweat and from evaporation through the lungs. Plain water is an appropriate fluid to consume for most exercise. Beverages containing carbohydrate and sodium are recommended for exercise lasting more than an hour.

13.6 Food and Drink to Maximize Performance

- Competitive endurance athletes may benefit from a dietary regimen called glycogen supercompensation (carbohydrate loading), which maximizes glycogen stores before an event.
- Meals eaten before competition should help ensure adequate hydration, provide moderate amounts of protein, be high enough in carbohydrate to maximize glycogen stores, be low in fat and fiber to speed gastric emptying, and satisfy the psychological needs of the athlete.
- During exercise, athletes need beverages and food to replace lost fluid and provide carbohydrate and sodium.
- Postcompetition meals should replace lost fluids and electrolytes, provide carbohydrate to restore muscle and liver glycogen, and provide protein for muscle protein synthesis and repair.

13.7 Ergogenic Aids: Do Supplements Enhance Athletic Performance?

- Many types of ergogenic aids are marketed to improve athletic performance. An individual risk–benefit analysis should be used to determine whether a supplement is appropriate for you.

- Vitamin and mineral supplements are usually not necessary for athletes who are consuming a diet that meets their energy needs.
- Protein supplements are popular for athletes trying to build muscle. Adequate protein is necessary to support muscle growth, but dietary protein can meet this need as effectively as the protein provided by supplements. Anabolic steroids combined with resistance-training exercise increase muscle size and strength, but these supplements are illegal and have dangerous side effects.
- Creatine and *ß*-alanine supplements have been shown to have benefits for improving performance in short-duration, high-intensity exercise.
- Caffeine use can improve performance in endurance activities. EPO increases endurance by boosting the number of red blood cells, but it is a banned substance that can contribute to excessive blood clotting, heart attacks, and strokes.
- A healthy diet is the base for successful athletic performance. Beverages and foods that supply fluids and energy can enhance performance, and there are a few supplements that benefit specific activities.

CHAPTER OUTLINE

14.1 The Physiology of Pregnancy
- Prenatal Growth and Development
- What Changes Occur in the Mother?
- Discomforts of Pregnancy
- Complications of Pregnancy

14.2 The Nutritional Needs of Pregnancy
- Energy Needs During Pregnancy
- Protein, Carbohydrate, and Fat Recommendations
- Water and Electrolyte Needs
- Micronutrient Needs During Pregnancy
- Meeting Nutrient Needs with Food and Supplements

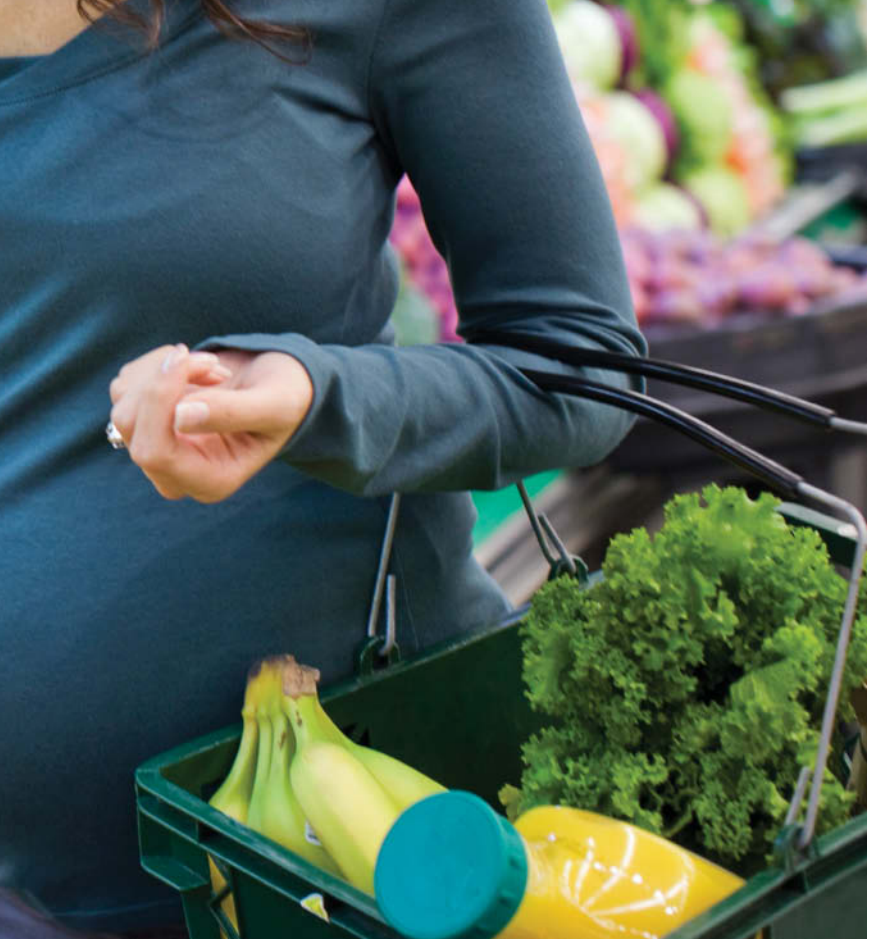
14.3 Factors That Increase the Risks of Pregnancy
- Maternal Nutritional Status
- Maternal Health Status
- Socioeconomic Factors
- Exposure to Toxic Substances

14.4 Lactation
- Milk Production and Letdown
- How Lactation Affects Maternal Nutrient Needs

14.5 The Nutritional Needs of Infancy
- Energy Needs During Infancy
- Fat Recommendations
- Carbohydrate Intake
- Protein Requirements
- Water Needs
- Micronutrient Needs of Infants
- Infant Growth and Nutritional Status

14.6 Feeding the Newborn
- Meeting Nutrient Needs with Breast-Feeding
- Meeting Nutrient Needs with Bottle-Feeding

(©iStockphoto)



UpperCut Images/Getty Images, Inc.

Nutrition During Pregnancy and Lactation

14

CASE STUDY

© Miroslav Ferkuniak/iStockphoto

Jasmine is 26 years old and expecting her first baby. She is at a healthy prepregnancy weight and exercises regularly by jogging or bicycling. At her initial prenatal visit, the obstetrician prescribes a prenatal supplement and gives her a pamphlet on nutrition during pregnancy. The pamphlet recommends that she gain 25 to 35 lb over the course of her pregnancy. Jasmine is concerned about this weight gain because she has a sister with three young children who is 25 lb heavier than she was before the birth of her first child eight years ago. Her sister also developed gestational diabetes during her last pregnancy. She had a difficult delivery because the baby was very large and she is still struggling to keep her blood sugar under control. Jasmine doesn't want to end up like that. She decides to continue to follow her usual exercise and eating patterns. After all, she reasons, the prenatal supplement will give her all the nutrients her baby needs.

By her next prenatal visit, during the fourth month of her pregnancy, Jasmine has gained only 1 lb. She tells the doctor that she has been limiting what she eats because she is afraid of gaining too much weight. He explains that a deficiency of nutrients or energy may cause birth defects or increase the risk of having a baby that is born too soon or too small. Her prenatal supplement is designed to be taken in addition to a healthy diet. Exercising regularly will help Jasmine avoid excess weight gain, but as her pregnancy progresses she may need to modify her exercise activities to ones that minimize the risk of injury. When Jasmine expresses her concern about gestational diabetes, the doctor tells her that keeping her weight gain within recommendations, limiting foods high in sugar, and exercising regularly will help to keep her blood sugar healthy. **He assures Jasmine that they will check for diabetes in a few weeks.**

14.1 The Physiology of Pregnancy

LEARNING OBJECTIVES

- Explain why the mother's nutrient intake during pregnancy is so important.
- Discuss the risks associated with gaining too little or too much weight during pregnancy.
- List some types of exercise that are appropriate for pregnant women.
- Describe some of the nutrition-related discomforts and complications of pregnancy.

conception The union of sperm and egg (ovum) that results in pregnancy.

lactation Milk production and secretion.

fertilization The union of sperm and egg (ovum).

oviduct or **fallopian tube** Narrow duct leading from the ovary to the uterus.

zygote The cell produced by the union of sperm and ovum during fertilization.

Pregnancy, from **conception** to birth, usually lasts 40 weeks in humans. During pregnancy, a single cell grows and develops into an infant that is ready for life outside the womb. This development requires a safe environment to which oxygen and nutrients are provided in the right amounts and from which waste products are removed. Many physiological changes take place in the mother to support prenatal development and prepare her for **lactation**.

Prenatal Growth and Development

Reproduction requires the **fertilization** of an egg, or ovum, from the mother by a sperm from the father. Fertilization, which occurs in the **oviduct** or **fallopian tube**, produces a single-celled **zygote** (Figure 14.1). The zygote travels down the mother's fallopian tube into

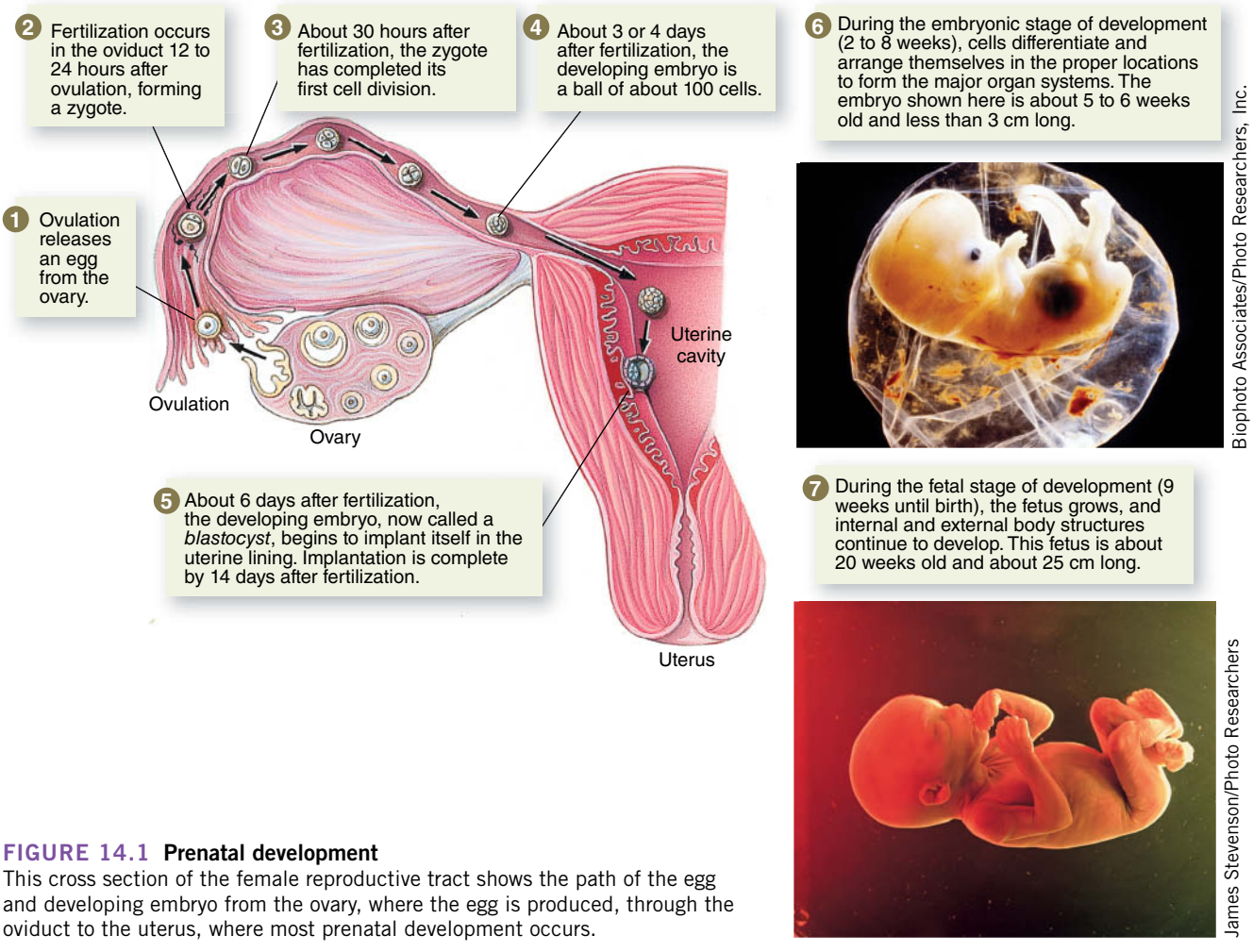


FIGURE 14.1 Prenatal development
This cross section of the female reproductive tract shows the path of the egg and developing embryo from the ovary, where the egg is produced, through the oviduct to the uterus, where most prenatal development occurs.

the uterus. Along the way, it divides many times to form a ball of smaller cells. In the uterus, the developing embryo, known as a *blastocyst,* imbeds in the uterine lining in a process called **implantation**.

implantation The process by which the developing embryo embeds in the uterine lining.

Prenatal growth and development continue after implantation. The cells differentiate into the multitude of specialized cell types that make up the human body, and arrange themselves in the proper shapes and locations to form organs and other structures. About two weeks after fertilization, implantation is complete and the developing offspring is known as an **embryo** (see Figure 14.1). The embryonic stage of development lasts until the eighth week after fertilization, when rudimentary organ systems have been formed. The embryo at this point is approximately 3 centimeters (cm) long (a little more than an inch) and has a beating heart. All major external and internal structures have been formed. Beginning at the ninth week of development and continuing until birth, the developing offspring is known as a **fetus** (see Figure 14.1). During the fetal period of development, structures that appeared during the embryonic period continue to grow and mature. Anything that interferes with development can cause birth defects. If the birth defects are severe, they may result in a **spontaneous abortion** or **miscarriage**.

embryo The developing human from two to eight weeks after fertilization. All organ systems are formed during this time.

fetus The developing human from the ninth week to birth. Growth and refinement of structures occur during this time.

spontaneous abortion or **miscarriage** Interruption of pregnancy prior to the seventh month.

The early embryo gets its nourishment by breaking down the lining of the uterus, but soon this source is inadequate to meet its growing needs. After about five weeks, the **placenta** takes over the role of nourishing the embryo (Figure 14.2). The placenta is a network of blood vessels and tissues that allows nutrients and oxygen to be transferred from mother to fetus and waste products to be transferred from the fetus to the mother's blood for elimination.

placenta An organ produced from both maternal and embryonic tissues. It secretes hormones, transfers nutrients and oxygen from the mother's blood to the fetus, and removes wastes.

The placenta is made up of tissue from both the mother and the fetus. The maternal portion of the placenta develops from the uterine lining. The fetal portion of the placenta develops from the outer layer of blastocyst cells. These cells divide to form branch-like projections that grow into the lining of the uterus, where they are surrounded by pools of maternal blood. The projections contain blood vessels that supply the developing fetus (see Figure 14.2). Although maternal and fetal blood do not mix, the proximity of fetal blood vessels to maternal blood allows nutrients and oxygen to easily pass from mother to baby, and allows carbon dioxide and other wastes to pass from baby to mother for elimination. The placenta also secretes hormones that are necessary to maintain pregnancy.

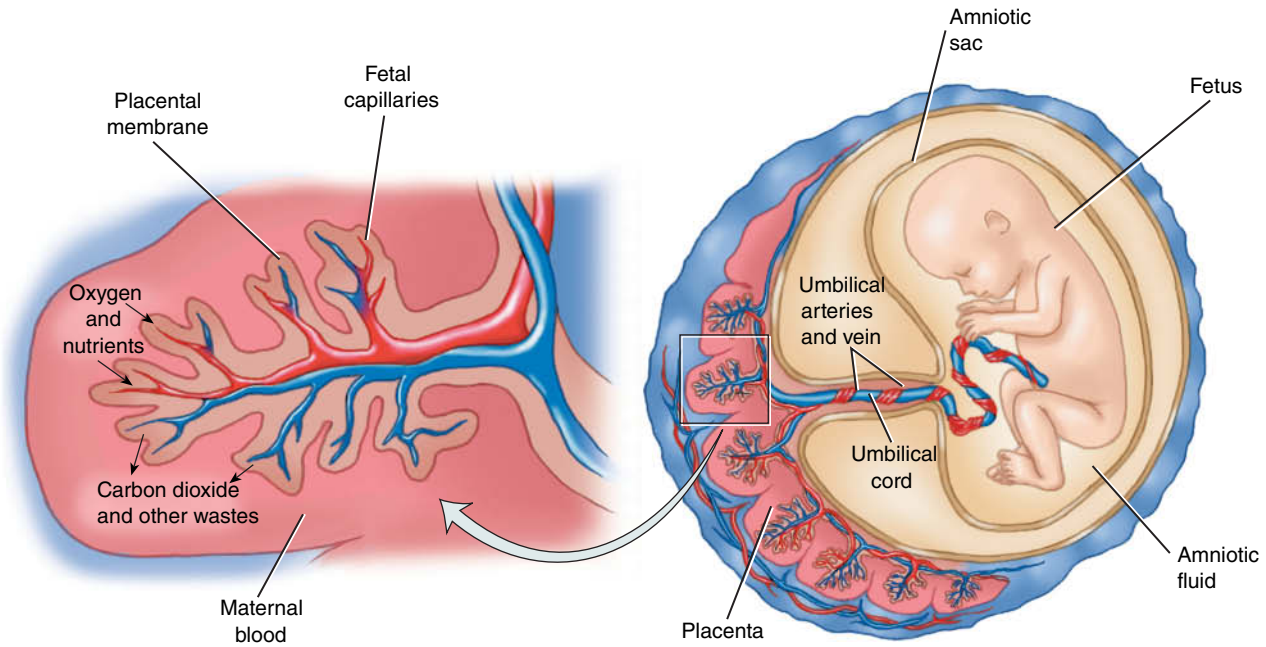


FIGURE 14.2 Placenta and amniotic sac
The placenta is made of branch-like projections that extend from the embryo into the uterine lining, placing maternal and fetal blood in proximity. The placenta allows the transfer of nutrients and wastes between mother and baby. Fetal blood travels to and from the placenta via the umbilical cord. The amniotic sac and the amniotic fluid, in which the baby floats, provide protection.

FIGURE 14.3
Premature infants
Low-birth-weight and very-low-birth-weight infants require special care and a special diet in order to grow and develop.

Sarah Leen/NG Image Collection

Pregnancy usually ends after 40 weeks of **gestation** with the birth of an infant weighing about 3 to 4 kg (6.6 to 8.8 lb).[1] Infants who are born on time but have failed to grow normally in the uterus are said to be **small for gestational age**. Those born before 37 weeks of gestation are said to be **preterm** or **premature**. Whether born too soon or just too small, **low-birth-weight** infants (those weighing less than 2.5 kg [5.5 lb] at birth) and **very-low-birth-weight** infants (those weighing less than 1.5 kg [3.3 lb]) are at increased risk for illness and early death.[2] They often require special care and a special diet in order to continue to grow and develop successfully. Survival improves with increasing gestational age and birth weight. Today, with advances in medical and nutritional care, infants born as early as 25 weeks of gestation and those weighing as little as 1 kg (2.2 lb) can survive (Figure 14.3).[3]

gestation The time between conception and birth, which lasts about nine months (or about 40 weeks) in humans.

small for gestational age A term used to describe a baby born at term weighing less than 2.5 kg (5.5 lb).

preterm or **premature** An infant born before 37 weeks of gestation.

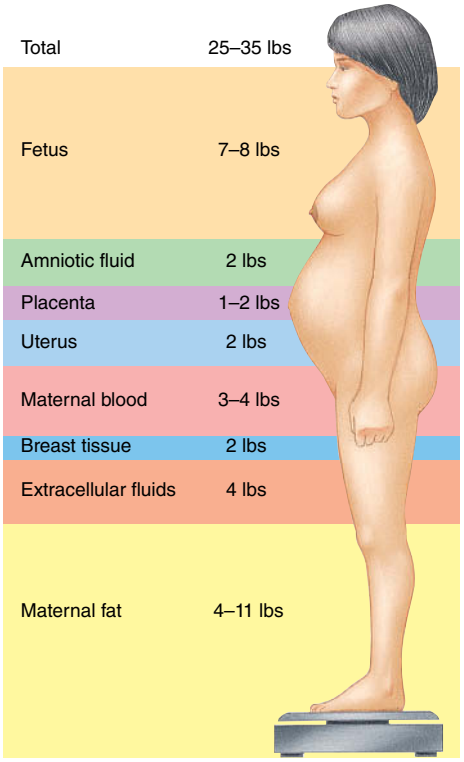
low birth weight A term used to describe an infant weighing less than 2.5 kg (5.5 lb) at birth.

very low birth weight A term used to describe an infant weighing less than 1.5 kg (3.3 lb) at birth.

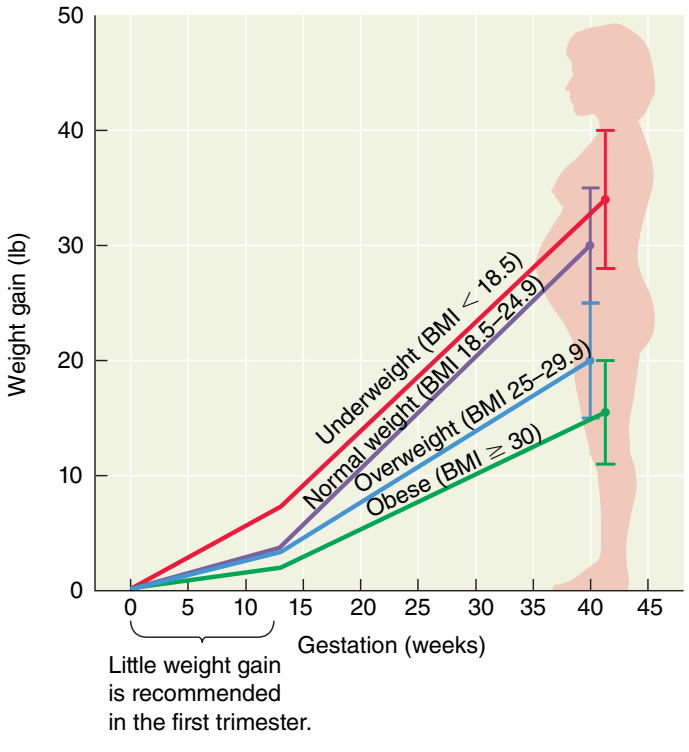
What Changes Occur in the Mother?

A woman's body undergoes many changes during pregnancy to support the growth and development of the embryo and fetus. These continuous physiological adjustments affect the metabolism and distribution of nutrients in her body. Maternal blood volume increases by 50%, and the heart, lungs, and kidneys work harder to deliver nutrients and oxygen and remove wastes. The placenta develops and the hormones it produces orchestrate other changes: They promote uterine growth; they relax muscles and ligaments to accommodate the growing fetus and allow for childbirth; they promote breast development; and they increase fat deposition to provide the energy stores that will be needed during late pregnancy and lactation. These changes result in weight gain and can affect the type and level of physical activity that is safe for the pregnant woman.

FIGURE 14.4 Composition and rate of weight gain in pregnancy



A. Weight gained during pregnancy is due to increases in the weight of the mother's tissues, as well as the weight of the fetus, placenta, and amniotic fluid.



B. A similar pattern of weight gain is recommended for women who are normal weight, underweight, overweight, or obese at the start of pregnancy, but total weight gain recommendations differ.

TABLE 14.1 Recommended Weight Gain During Pregnancy[1,4]

Prepregnancy BMI	Total weight gain (kg)	Total weight gain (lb)	Rates of weight gain[a] (2nd and 3rd trimesters) Mean (range) (kg/week)	Rates of weight gain[a] (2nd and 3rd trimesters) Mean (range) (lb/week)
Underweight (< 18.5 kg/m^2)	12.5–18	28–40	0.51 (0.44–0.58)	1 (1–1.3)
Normal weight (18.5–24.9 kg/m^2)	11.5–16	25–35	0.42 (0.35–0.50)	1 (0.8–1)
Overweight (25.0–29.9 kg/m^2)	7–11.5	15–25	0.28 (0.23–0.33)	0.6 (0.5–0.7)
Obese (≥ 30.0 kg/m^2)	5–9	11–20	0.22 (0.17–0.27)	0.5 (0.4–0.6)

[a]Calculations assume a 0.5- to 2-kg (1.1- to 4.4-lb) weight gain in the first trimester.

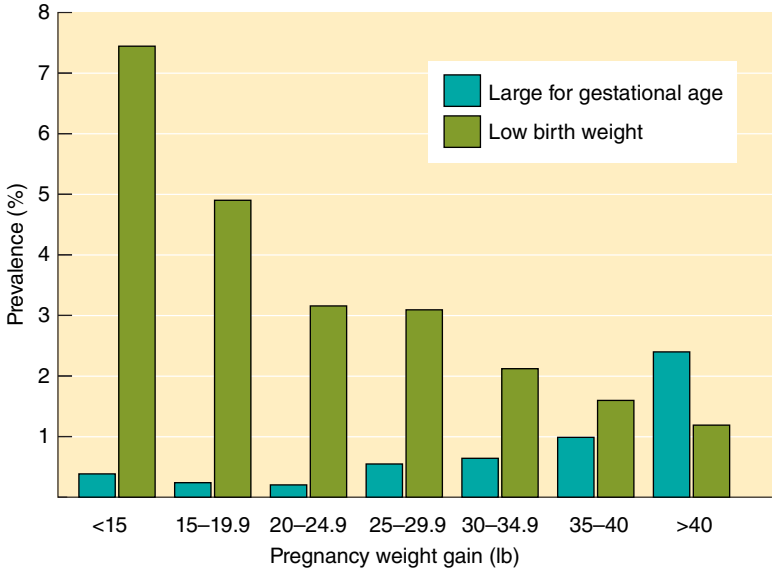
Weight Gain During Pregnancy Gaining the right amount of weight during pregnancy is essential to the health of both mother and fetus. The recommended weight gain for healthy, normal-weight women is 25 to 35 lb (11.4 to 15.9 kg). Typically, the weight of the infant at birth is about 25% of the total pregnancy weight gain. The placenta, amniotic fluid, and changes in maternal tissues account for the rest. This includes increases in the size of the uterus and breasts, expansion of blood and extracellular fluid volume, and deposition of fat stores (Figure 14.4A). The rate of weight gain is as important as the total weight gain (Table 14.1). Little gain is expected in the first three months, or **trimester**, of pregnancy—usually about 2 to 4 lb (0.9 to 1.8 kg). In the second and third trimesters, when the fetus grows from less than 1 lb to 6 to 8 lb, the recommended maternal weight gain is about 1 lb (0.45 kg)/week. Women who are underweight and women who are overweight or obese at conception should still gain weight at a slow, steady rate (Figure 14.4B). Weight gains of up to 40 lb (18 kg) are recommended for women who begin pregnancy underweight. Women who are overweight or obese should gain less. Additional weight gain is recommended for multiple-birth pregnancies.[1]

trimester A term used to describe each third, or three-month period, of a pregnancy.

Being underweight by 10% or more at the onset of pregnancy or gaining too little weight during pregnancy increases the risk of producing a low-birth-weight baby or preterm baby (Figure 14.5).[2,5] It can also increase the child's risk of developing heart disease or diabetes later in life.[2] Excess weight, whether present before conception or gained during pregnancy, can also compromise the outcome of the pregnancy. The mother's risks for high blood pressure, diabetes, difficult delivery, and **cesarean section** are increased by excess weight, as is the risk of having a **large-for-gestational-age** baby (see Figure 14.5).[6,7] Maternal obesity may also increase the risk of neural tube defects and fetal death.[2,8] Excessive prenatal weight gain also increases the mother's long-term risk of obesity, and it may increase the risk that the baby will be overweight and have other health problems later in life.[9,10] Despite this,

cesarean section The surgical removal of the fetus from the uterus.

large for gestational age A term used to describe an infant weighing more than 4 kg (8.8 lb) at birth.



ANALYZE THE DATA

Based on the information in this graph, how much weight would you recommend that a woman with a BMI of 24 kg/m^2 gain during pregnancy?

FIGURE 14.5 Relationship between maternal weight gain and birth weight
Gaining less or more than the recommended amount of weight during pregnancy increases the incidence of low-birth-weight and large-for-gestational-age babies, respectively.

dieting during pregnancy is not advised even for women who are obese. If possible, excess weight should be lost before the pregnancy begins or, alternatively, after the child is born and weaned.

Some women are concerned that weight gained during pregnancy will be permanent, but most women lose all but about 2 lb within a year of delivery. Approximately 10 lb are lost at birth from the weight of the baby, amniotic fluid, and placenta. In the week after delivery, another 5 lb of fluid are typically lost. Once this initial fluid and tissue weight is lost, further weight loss requires that energy intake be less than energy output. After the mother has recovered from delivery, a balanced, reduced-calorie diet combined with moderate exercise will promote weight loss and the return of muscle tone.

Physical Activity During Pregnancy For healthy, well-nourished women, carefully chosen moderate exercise is recommended during and after pregnancy.[2] Physical activity during pregnancy improves overall fitness, reduces stress, prevents excess weight gain, prevents low back pain, improves digestion, reduces constipation, improves mood and body image, and speeds recovery from childbirth. Some evidence suggests that physical activity may reduce the risk of pregnancy complications and the length of labor.[11] In healthy women, moderate-intensity activity during pregnancy does not increase risk of low birth weight, preterm delivery, or early pregnancy loss, but too much strenuous exercise has the potential to harm the fetus by reducing the amount of oxygen and nutrients it receives or by increasing body temperature. Therefore, guidelines have been developed to minimize the risks and maximize the benefits of exercise during pregnancy (Table 14.2). All pregnant women should check with their physicians before engaging in any exercise program.

Women who were physically active before their pregnancy can continue their exercise programs; those who were inactive should start slowly with a goal of exercising for 150 minutes each week.[11] Because women weigh more during pregnancy and carry that weight in the front of the body, where it can interfere with balance and put stress on the bones, joints, and muscles, the risk of exercise-related injury is increased. Low-intensity, low-impact activities such as walking are ideal. Activities that have a risk of abdominal trauma, falls, or joint stress, such as contact and racquet sports, should be avoided.[11] Exercise in the water is recommended because the body's buoyancy in water compensates for the changes in weight distribution. To ensure adequate delivery of oxygen and nutrients to the fetus, intense exercise should be limited during pregnancy. To prevent overheating, plenty of fluids should be consumed, and exercise should be carried out in a well-ventilated environment.

Discomforts of Pregnancy

The physiological changes that occur during pregnancy can cause uncomfortable side effects in the mother. Some are caused by changes in fluid distribution, others by hormonal changes that

TABLE 14.2 Guidelines for Physical Activity During Pregnancy

Do . . .	Don't . . .
Obtain permission from your health-care provider before beginning an exercise program.	Exercise strenuously during the first trimester.
Increase activity gradually if you were inactive before pregnancy.	Exercise strenuously for more than 15 minutes at a time during the second and third trimesters.
Exercise regularly rather than intermittently.	Exercise to the point of exhaustion.
Stop exercising when fatigued.	Exercise lying on your back after the first trimester.
Choose non–weight-bearing activities, such as swimming, that entail minimal risk of falls or abdominal injury.	Scuba dive or engage in activities that entail risk of abdominal trauma, falls, or joint stress.
Drink plenty of fluids before, during, and after exercise.	Exercise in hot or humid environments.

Tracy Frankel/The Image Bank/Getty Images, Inc.

affect the digestive tract. Most of these problems are minor, but in some cases they may endanger the mother and the fetus.

P. Marazzi/Science Photo Library/Photo Researchers, Inc.

FIGURE 14.6 Edema
Edema in the feet and ankles is common during pregnancy. The swelling may be reduced by elevating the feet.

Why Edema Is Common During Pregnancy During pregnancy, blood volume expands to nourish the fetus, but this expansion may also cause the accumulation of extracellular fluid in the tissues, known as **edema**. Edema is common in the feet and ankles during pregnancy because the growing uterus puts pressure on the veins that return blood from the legs to the heart. This causes blood to pool in the legs, forcing fluid from the veins into the tissues of the feet and ankles (Figure 14.6). Edema can be uncomfortable, but does not increase medical risks unless it is accompanied by a rise in blood pressure. Reducing fluid and sodium intake below the amount recommended for the general population is not recommended.

How Morning Sickness Affects Health **Morning sickness** is a syndrome of nausea and vomiting that occurs in about 70% of women during pregnancy.[12] The incidence peaks at about 8 to 12 weeks of pregnancy and symptoms usually resolve by week 20. The term "morning sickness" is somewhat of a misnomer, because symptoms can occur anytime during the day or night. Although the cause is unknown, this nausea and vomiting is hypothesized to be related to the hormonal changes of pregnancy. The symptoms may be alleviated to some extent by eating small frequent snacks of dry starchy foods, such as plain crackers or bread. In most women, symptoms are mild and do not affect maternal or fetal health. Up to 2% of pregnant women, however, have a severe and intractable form of nausea and vomiting called *hyperemesis gravidarum* that can result in weight loss, nutritional deficiencies, and abnormalities in fluid and electrolyte levels and acid–base balance. Treatment may require intravenous nutrition to ensure that needs are met, and medications to reduce nausea.[13]

edema Swelling due to the buildup of extracellular fluid in the tissues.

morning sickness Nausea and vomiting that affects many women during the first few months of pregnancy and in some women can continue throughout the pregnancy.

Why Heartburn Is a Problem for Pregnant Women Heartburn, a burning sensation caused by stomach acid leaking up into the esophagus, is another common digestive complaint during pregnancy because the hormones produced to relax the muscles of the uterus also relax the muscles of the gastrointestinal tract, including the gastroesophageal sphincter. This involuntary relaxation of the gastroesophageal sphincter allows the acidic stomach contents to back up into the esophagus, causing irritation. The problem gets more severe as pregnancy progresses because the growing baby crowds the stomach (Figure 14.7). The fuller the stomach, the more likely its contents are to back up into the esophagus. Heartburn can be reduced by avoiding substances that are known to cause it, such as caffeine and chocolate, and by consuming many small meals throughout the day rather than a few large meals. Limiting intake of high-fat foods that leave the stomach slowly, such as fried foods, rich sauces, and desserts, can also help reduce heartburn. Because a reclining position makes it easier for acidic juices to flow into the esophagus, remaining upright after eating, limiting eating in the hours before bedtime, and sleeping with extra pillows to produce a semi-reclining sleep position can also reduce heartburn.

How Pregnancy Contributes to Constipation and Hemorrhoids Constipation is a frequent complaint during pregnancy. The pregnancy-related hormones that cause muscles to relax also decrease intestinal motility and slow transit time. Constipation is a more common problem late in pregnancy, when the enlarging uterus puts pressure on the gastrointestinal tract (see Figure 14.7). Iron supplements prescribed during pregnancy also contribute to constipation. Maintaining a moderate level of physical activity and consuming plenty of water and other fluids along with high-fiber foods, such as whole grains, vegetables, and fruits, are recommended to prevent constipation. Hemorrhoids are also more common during pregnancy, as a result of both constipation and physiological changes in blood flow.

Complications of Pregnancy

Most of the 3.9 million women who give birth every year in the United States have healthy pregnancies. However, about 11% of babies are born too soon, 8% have low or very low

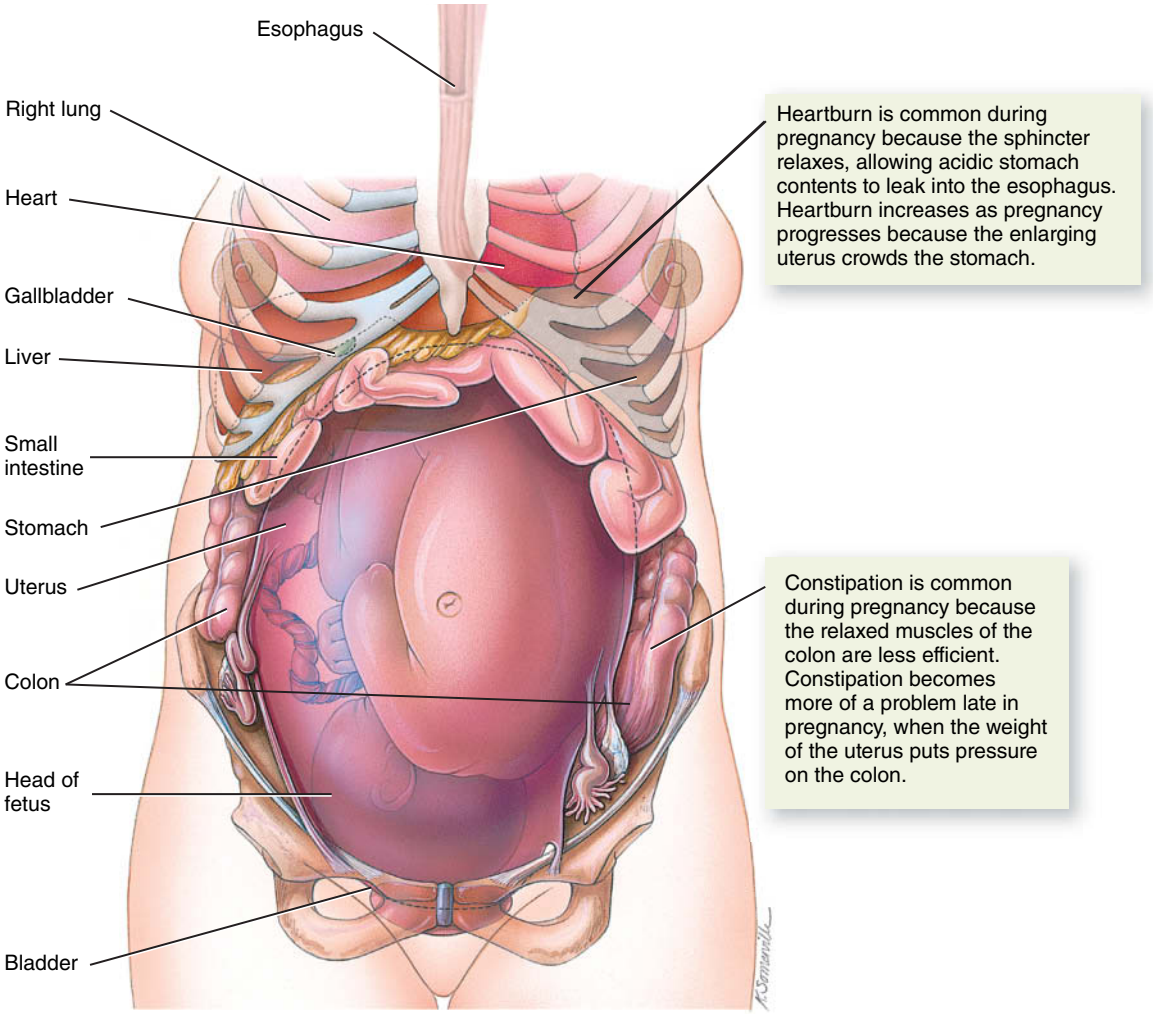


FIGURE 14.7 Crowding of the gastrointestinal tract
During pregnancy the uterus enlarges and pushes higher into the abdominal cavity, exerting pressure on the stomach and intestines. This contributes to both heartburn and constipation.

hypertensive disorders of pregnancy High blood pressure during pregnancy that is due to chronic hypertension, gestational hypertension, preeclampsia–eclampsia, or preeclampsia superimposed on chronic hypertension.

gestational hypertension The development of hypertension after the 20th week of pregnancy.

preeclampsia A condition characterized by an increase in body weight, elevated blood pressure, protein in the urine, and edema. It can progress to **eclampsia**, which causes seizures and can be life threatening to mother and fetus.

birth weights, and about 6 out of 1000 of those born alive die in their first year of life. Complications also impact maternal health; about 17 out of every 100,000 women in the United States die as a result of childbirth. If complications that occur during pregnancy are caught early, they can usually be managed, resulting in a healthy delivery for mother and baby (Figure 14.8).[14]

High Blood Pressure About 5 to 10% of pregnant women in the United States experience high blood pressure during pregnancy.[15] The term **hypertensive disorders of pregnancy** refers to a spectrum of conditions involving elevated blood pressure during pregnancy. It accounts for more than 12% of pregnancy-related maternal deaths in the United States.[16]

High blood pressure that is present before the pregnancy or diagnosed before 20 weeks of gestation is referred to as chronic hypertension.[17,18] **Gestational hypertension** is an abnormal rise in blood pressure that occurs after the 20th week of pregnancy and resolves within 12 weeks of birth; it may signal the potential for a more serious condition called **preeclampsia**.[17,18] Preeclampsia is characterized by symptoms that may include high blood pressure, severe headaches, changes in vision, abdominal pain, fluid retention, swelling of the hands and feet, and excretion of protein in the urine; it can result in weight gain of several pounds within a few days. It is dangerous to the baby because it reduces blood flow to the placenta, and it is dangerous to the mother because it can progress to a more severe condition called **eclampsia**, in which life-threatening seizures occur. Preeclampsia can often be managed with bed rest and careful medical monitoring, but eclampsia may necessitate early delivery of the baby. The condition

usually resolves after delivery. Preeclampsia and eclampsia are common in mothers under 18 and over 35 years of age, low-income mothers, and mothers with obesity, chronic hypertension, or kidney disease.

The causes of preeclampsia are not fully understood. At one time, low-sodium diets were prescribed to prevent it, but studies have not found them to be beneficial in lowering blood pressure or preventing this condition.[19] Calcium may play a role in preventing the hypertensive disorders of pregnancy. Women with a high intake of calcium have a low incidence of these disorders, and calcium supplements have been found to reduce the risk of preeclampsia in high-risk women.[20] Although calcium supplements are not routinely recommended for healthy pregnant women, pregnant teens, individuals with inadequate calcium intake, and women who are known to be at risk of developing hypertension during pregnancy may benefit from additional dietary calcium.[20]

Faye Norman/Science Photo Library/Photo Researchers, Inc.

FIGURE 14.8 Prenatal care
Adequate prenatal care, which monitors the mother's blood pressure, weight, and blood sugar and the baby's size and heartbeat, can allow early identification and treatment of pregnancy complications.

Gestational Diabetes Mellitus Consistently elevated blood glucose levels during pregnancy in a woman without previously diagnosed diabetes is known as **gestational diabetes mellitus**. It occurs in about 9% of all pregnancies and is most common in women who are obese and those with a family history of type 2 diabetes.[21,22] It occurs more frequently among African American, Hispanic/Latino American, and Native American women than among Caucasian women. This form of diabetes usually disappears when the pregnancy is completed, but 5 to 10% of women are diagnosed with type 2 diabetes after delivery, and having had gestational diabetes increases the risk of developing type 2 diabetes later in life (see Chapter 4).[22] Gestational diabetes increases risks to the baby. Because glucose in the mother's blood passes freely across the placenta, when the mother's blood levels are high, the growing fetus receives extra glucose. This extra energy promotes rapid growth, resulting in babies who are large for gestational age and consequently at increased risk of complications during delivery. Babies born to mothers with gestational diabetes are also at increased risk of developing diabetes as adults. As with other types of diabetes, the treatment of gestational diabetes involves consuming a carefully planned diet, maintaining moderate daily exercise, and in some cases using medications to control blood glucose.

gestational diabetes mellitus A consistently elevated blood glucose level that develops during pregnancy and returns to normal after delivery.

14.2 The Nutritional Needs of Pregnancy

LEARNING OBJECTIVES

- Discuss the recommendations for energy intake during each trimester.
- Compare the protein needs of pregnant women with those of nonpregnant women.
- Explain why water needs increase during pregnancy.
- Describe the potential effects of too little folic acid during pregnancy.
- Distinguish the role of food versus supplements for meeting nutrient needs during pregnancy.

To produce a healthy baby, maternal intake must supply all the nutrients needed to provide for the growth and development of the fetus while continuing to meet the mother's needs. Because the increased need for energy is proportionately smaller than the increased need for protein, vitamins, and minerals, a well-balanced, nutrient-dense diet is required.

Energy Needs During Pregnancy

Energy needs increase during pregnancy to deposit and maintain the new fetal and maternal tissues. The estimated energy requirement (EER) for pregnancy is calculated by totaling the energy needs of nonpregnant women, the increase in energy needs due to pregnancy, and the energy deposited in tissues.[23] During the first trimester, total energy expenditure changes little, so the

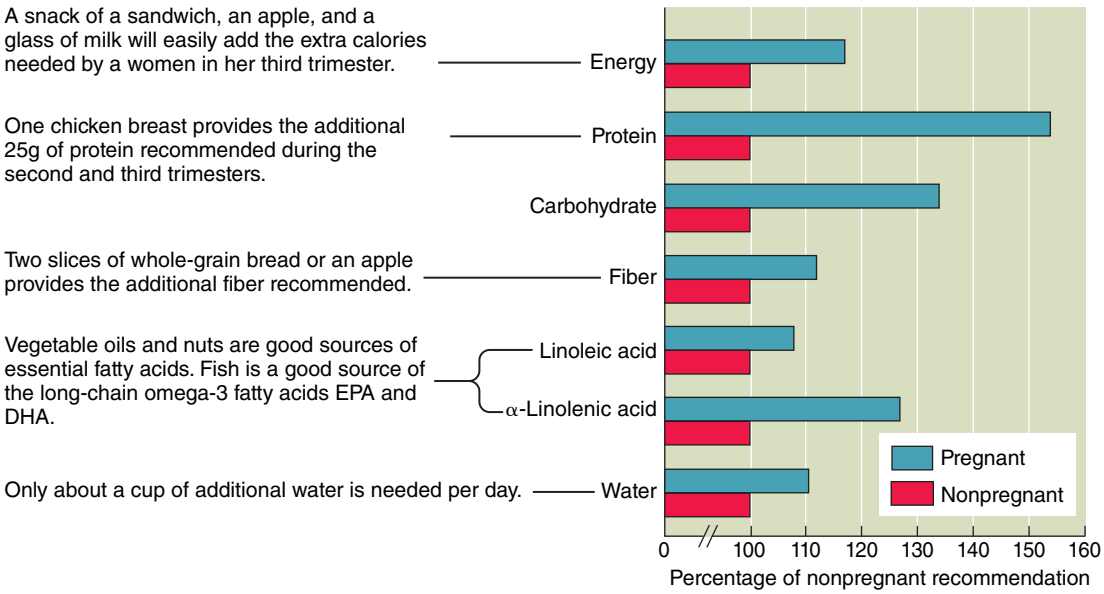


FIGURE 14.9 Energy and macronutrient needs during pregnancy
This graph illustrates the differences between the recommended daily intake of energy, protein, carbohydrate, fiber, essential fatty acids, and water for nonpregnant 25-year-old women and pregnant 25-year-old women during the third trimester of pregnancy.

EER is not increased above nonpregnant levels. During the second and third trimesters, an additional 340 and 452 kcal/day, respectively, are recommended (Figure 14.9).

Protein, Carbohydrate, and Fat Recommendations

The RDA for protein is increased during pregnancy (see Figure 14.9). The additional protein is needed because protein is essential for the formation and growth of new cells. During pregnancy, the placenta develops and grows, the uterus and breasts enlarge, and a single cell develops into a fully formed infant. An additional 25 g of protein per day above the RDA for nonpregnant women, or 1.1 g/kg of body weight per day, is recommended in the second and third trimesters of pregnancy.[23] For example, for a woman weighing 136 lb (62 kg), protein needs increase to a total of about 75 g/day. This amount of protein would be provided by a diet that includes 3 cups of milk or yogurt, 4 oz of meat, and ¾ cup of beans.

The RDA for carbohydrate is increased by 45 g/day during pregnancy to provide sufficient glucose to fuel the fetal and maternal brains. Therefore, the RDA for carbohydrate during pregnancy is 175 g/day. This is well below the typical intake of about 300 g/day, and therefore most women do not need to consciously increase carbohydrate intake. The AI for fiber is increased to 28 g/day.

Although total fat intake does not need to increase during pregnancy, more of the essential fatty acids linoleic and α-linolenic acid are recommended because these are incorporated into the placenta and the fetal tissues. The long-chain polyunsaturated fatty acids docosahexanoic acid (DHA) and arachidonic acid (ARA) are important because they not only support maternal health but are essential for the development of the eyes and nervous system in the fetus.[24] Since there is insufficient data to determine how much is required to meet these needs, AIs for the essential fatty acids have been established based on the median intake in the United States.

Despite increases in the recommended intakes of protein, carbohydrate, and specific fatty acids during pregnancy, the macronutrient distribution of the diet should be about the same as that recommended for the general population. If the additional energy and protein needed during pregnancy come from nutrient-dense choices, the diet will provide the additional carbohydrate and fatty acids needed for a healthy pregnancy.

Water and Electrolyte Needs

The need for water increases during pregnancy because of the increase in blood volume, the production of amniotic fluid, and the needs of the fetus. Throughout pregnancy a woman will accumulate about 6 to 9 L of water. Some is intracellular, but most is due to increases in the volume of blood and interstitial fluid. The need for water from food and beverages is therefore increased from 2.7 L/day in nonpregnant women to 3 L/day.[19] This is equivalent to drinking a little more than an extra cup a day. Despite changes in the amount and distribution of body water during pregnancy, there is no evidence that the requirements for potassium, sodium, or chloride are different from those of nonpregnant women.[19]

Micronutrient Needs During Pregnancy

The need for many vitamins and minerals is increased during pregnancy (**Figure 14.10**). To form new maternal and fetal cells and to meet the needs for protein synthesis in fetal and maternal tissues, the requirements for folate, vitamin B_{12}, vitamin B_6, zinc, and iron increase. To provide for the rise in energy utilization, the requirements for thiamin, niacin, and riboflavin increase. Adequate calcium, vitamin D, and vitamin C are needed for the growth and development of bone and connective tissue. For many of these nutrients, intake is easily increased when energy intake rises to meet needs, but for others there is a risk that inadequate amounts will be consumed.

Calcium The fetus retains about 30 g of calcium over the course of gestation. Most of the calcium is deposited in the last trimester, when the fetal skeleton is growing most rapidly and the teeth are forming. However, the RDA is not increased during pregnancy because calcium absorption doubles.[25] Absorption increases during pregnancy due the rise in estrogen and an increase in the concentration of active vitamin D in the blood. Because

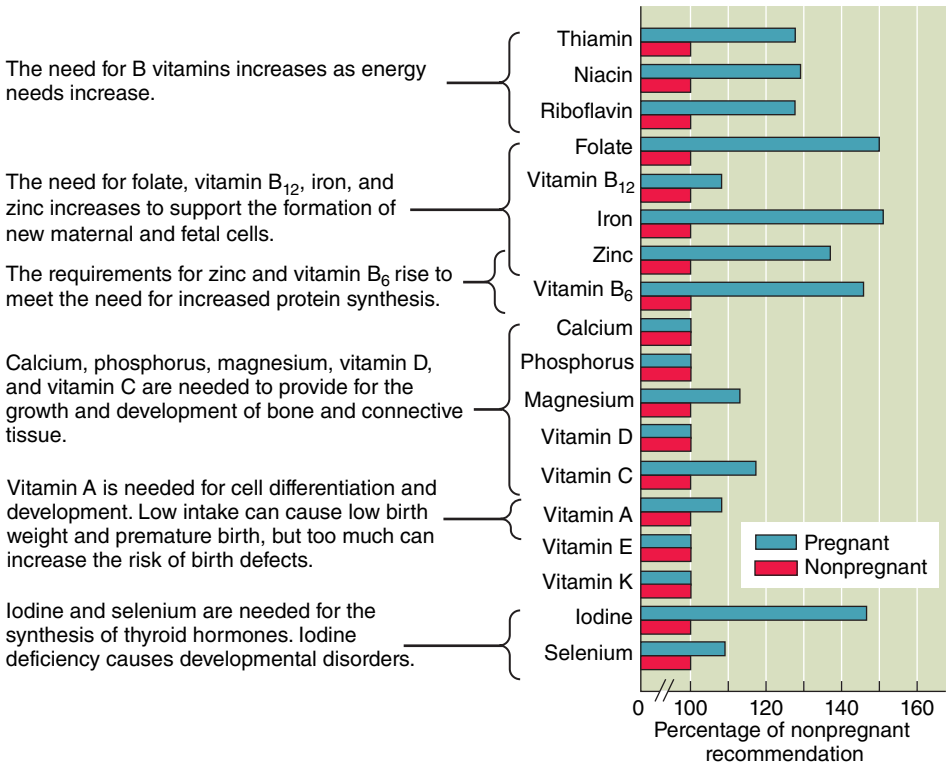


FIGURE 14.10 Vitamin and mineral needs during pregnancy
This graph compares the recommended micronutrient intakes for nonpregnant 25-year-old women and pregnant 25-year-old women during the third trimester of pregnancy.

THINK CRITICALLY

If the RDA for calcium is not increased during pregnancy, where does the calcium for the fetal skeleton come from?

of the increase in absorption, the increased need for calcium during pregnancy does not cause a decrease in bone density in the short term or increase the risk of fractures and osteoporosis later in life.[26,27] The RDA for calcium for pregnant women ages 19 and older—1000 mg/day—is the same as for nonpregnant women. The RDA can be met by consuming three to four servings of milk or other dairy products daily. Women who do not consume dairy products can meet their calcium needs with calcium-rich vegetables, fish consumed with bones, calcium-fortified foods, or calcium supplements. Low calcium intake may increase the risk of preeclampsia.[20]

Vitamin D Adequate vitamin D is essential to ensure efficient calcium absorption. The RDA for vitamin D during pregnancy is 600 IU (15 μg)/day, the same as for nonpregnant women.[25] This is based on the assumption of minimal sun exposure. Pregnant women who receive regular exposure to sunlight can synthesize sufficient vitamin D. If exposure to sunlight is limited, dietary sources such as fatty fish, milk, and other fortified foods, or supplements, must supply the needed amounts. A recent study has found that almost 70% of pregnant women have low blood levels of vitamin D, and the percentage is much higher among African American women.[28] African American women are at increased risk of deficiency not only because their darker pigmentation reduces the synthesis of vitamin D in the skin, but also because milk intake is frequently reduced due to lactose intolerance. Some prenatal supplements provide only 400 IU (10 μg) of vitamin D, which is two thirds of the RDA.

Vitamin C Vitamin C is important for bone and connective tissue formation because it is needed for the synthesis of collagen, which gives structure to skin, tendons, and the protein matrix of bones. Vitamin C deficiency during pregnancy increases the risk for premature birth and preeclampsia. The RDA is increased by 10 mg/day during pregnancy.[29] The requirement for vitamin C can easily be met by including citrus fruits and juices in the diet, and supplements are generally not necessary.

neural tube The portion of the embryo that develops into the brain and spinal cord.

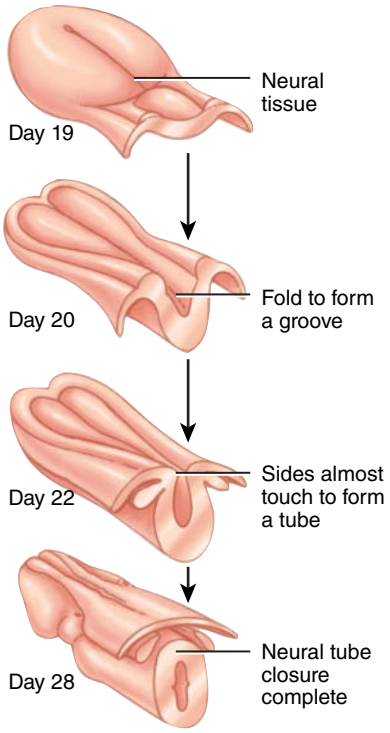


FIGURE 14.11 Neural tube formation
The neural tube develops from a flat plate of neural tissue.

Folate Folate is needed for the synthesis of DNA and thus for cell division. During pregnancy, cells multiply to form the placenta, expand maternal blood, and allow fetal growth. Adequate folate intake is crucial even before conception because rapid cell division occurs in the first days and weeks of pregnancy.

If maternal folate intake is low, there is an increased risk of fetal abnormalities that involve the formation of the **neural tube**. During development, a groove forms in the neural tissue. The neural tube is created when the sides of the groove rise and fold together (Figure 14.11). This neural tube closure occurs between 21 and 28 days of development. If it does not occur normally, the infant will be born with a neural tube defect. These defects include anencephaly, in which the brain and skull do not develop normally, and spina bifida, a condition in which the vertebrae do not close completely, causing part of the spinal cord to be exposed (see Chapter 8).

Because the neural tube closes so early in development, often before a woman even knows she is pregnant, the DRIs recommend that women capable of becoming pregnant consume 400 μg/day of synthetic folic acid from fortified foods, supplements, or a combination of the two, in addition to consuming a varied diet rich in natural sources of folate (see Chapter 8, *Critical Thinking: Meeting Folate Recommendations*). Since the folic acid fortification of enriched grains began in 1998, the incidence of neural tube defects in the United States has decreased by about 30%.[30] Reductions ranging from 19 to 55% have been observed in other countries where folic acid fortification has been introduced (see **Science Applied: Folate: Reducing Birth Defects through Fortification**).[31]

Adequate folate continues to be important even after the neural tube closes. Cell division is rapid in both embryonic and fetal development, and folate is central because of its role in DNA synthesis. Marginal folate status can impair growth in both the fetus and the placenta. If folate is inadequate during pregnancy, macrocytic

SCIENCE APPLIED

Folate: Reducing Birth Defects through Fortification

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

Until the late 1990s, neural tube defects (NTDs), such as spina bifida and anencephaly, affected approximately 3900 pregnancies in the United States each year. For decades, researchers had suspected that NTDs might be related to the mother's dietary intake. Today, public health policies mandate the fortification of certain foods with folic acid, the synthetic form of folate, preventing birth defects in thousands of babies.

THE SCIENCE

The link between maternal folate status and NTDs was identified in the 1970s when lower first-trimester red blood cell folate concentrations were found in women who later gave birth to NTD-affected babies.[34] An intervention study completed in 1980 demonstrated that folic acid supplementation in early pregnancy reduced the incidence of NTDs in women who had previously given birth to a baby with an NTD.[35] These findings were supported by a second, large-scale study, in which nonpregnant women with a history of NTD-affected pregnancies were randomly assigned to receive folic acid, other supplemental vitamins, or a placebo. This trial was stopped early when researchers concluded that folic acid supplementation alone reduced NTD recurrence by 71%.[36]

A link between NTDs and folic acid was now clear, but early trials used 800 μg of folic acid. Could a smaller amount be as effective? Also, would folic acid supplementation prevent the first occurrence of NTDs? To answer these questions, women who had no previous NTD–affected pregnancies and were planning a pregnancy were randomly assigned to receive folic acid or a placebo for at least one month before conception and until at least the date of the second missed menstrual cycle.[37] The study evaluated 5453 pregnancies. In the 2391 women receiving the placebo, six babies were born with NTDs; in the 2471 women in the supplement group, there were no NTDs.[38] This and other studies helped determine that 400 μg of supplemental folic acid dramatically reduced the incidence of NTDs.[39,40]

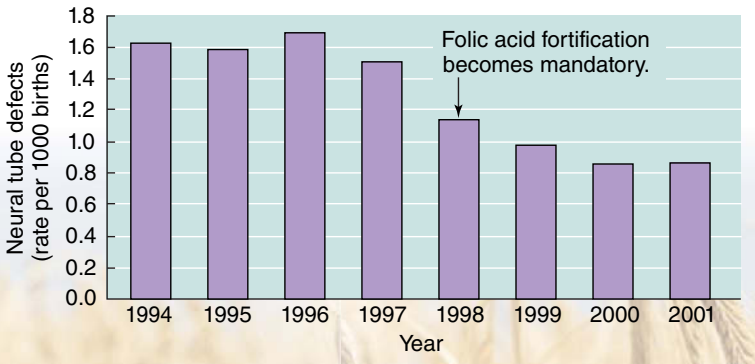
THE APPLICATION

These results led the Centers for Disease Control and Prevention and the U.S. Public Health Service to recommend that all women of childbearing age who are capable of becoming pregnant consume 400 μg/day of folic acid. But how could the population's folate intake be increased? Educating women to consume foods high in folate would be costly and ineffective. Folic acid supplements were recommended, but after five years only one-third of women of childbearing age were consuming a supplement containing the recommended amount.[41] Therefore, it was concluded that the most reliable way to increase folate consumption was through food fortification.

Fortification of the food supply requires a careful analysis to determine how much of the nutrient to add to provide the needed benefit without undue risk. The right amount of supplemental folic acid could reduce the incidence of NTD-affected pregnancies, but because a high folic acid intake can mask the symptoms of vitamin B_{12} deficiency, a level of fortification needed to be chosen that would reduce NTDs without compromising the elderly population at risk for vitamin B_{12} deficiency.

The foods chosen for fortification were enriched grain products such as bread, flour, cornmeal, pasta, grits, and rice. These products are regularly consumed by the target population—women of childbearing age of all races and cultures. The folic acid could be added to these grains while they were being enriched with other nutrients. The amount added, 140 μg per 100 g of grain product, was chosen because it balanced the need to provide enough folic acid to reduce the risk of NTDs with the possibility of masking vitamin B_{12} deficiency. In 1998, the FDA mandated that folic acid be added to all enriched grains and cereal products. The success of the folic acid fortification program can be seen in the decline in the estimated number of NTD-affected pregnancies (see graph).[30]

THINK CRITICALLY: Suggest some possible reasons why fortifying grains with folic acid has not completely eliminated neural tube defects.



anemia—the type of anemia characterized by abnormally large red blood cells—may result (see Chapter 8). Low dietary folate intakes and low circulating folate levels are associated with increased risk of preterm delivery, low birth weight, and fetal growth retardation.[32] Thus, to maintain red blood cell folate levels in pregnant women, the RDA for folate is set at 600 μg dietary folate equivalents per day.[33] Natural sources of folate include orange juice, legumes, leafy green vegetables, and organ meats. A half cup of legumes plus a cup of raw spinach provide about a third of the RDA. Fortified sources include enriched breads, cereals, and other grain products; a serving of fortified cereal provides from 25 to 100% of the RDA. Folic acid supplements can also be used to meet recommendations. Most prenatal supplements contain 400 μg of folic acid.

Vitamin B_{12} Vitamin B_{12} is essential for the regeneration of active forms of folate. A deficiency of vitamin B_{12} can therefore result in macrocytic anemia in the mother and impaired growth and cognitive development in the fetus.[42] Vitamin B_{12} is transferred from the mother to the fetus during pregnancy. Based on the amount transferred and the increased efficiency of vitamin B_{12} absorption that occurs during pregnancy, the RDA for pregnancy is set at 2.6 μg/day.[33] This recommendation is easily met by a diet containing even small amounts of animal products. Vegetarian diets are generally safe for pregnant women, but vegans must consume foods fortified with vitamin B_{12} or take vitamin B_{12} supplements daily to meet the needs of mother and fetus.

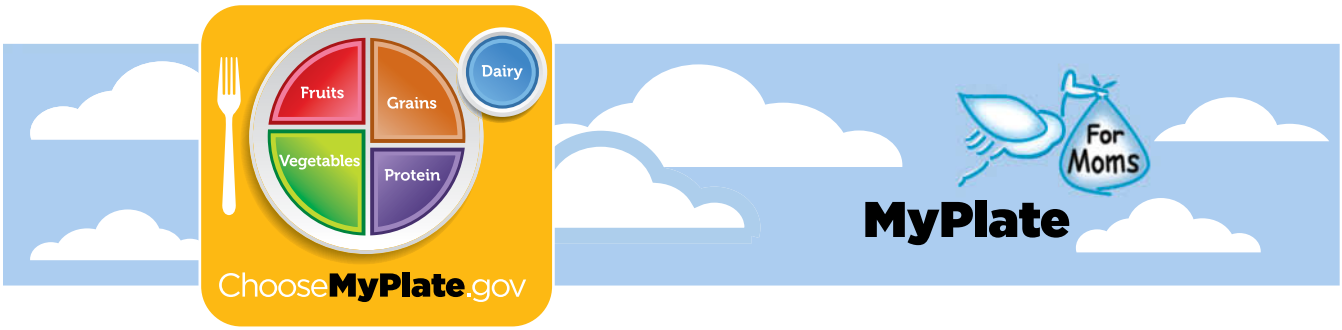
Zinc Zinc is involved in the synthesis of DNA, RNA, and proteins. It is therefore extremely important for growth and development. Zinc deficiency during pregnancy is associated with an increased risk of fetal malformations, prematurity, and low birth weight.[43] Because zinc absorption is inhibited by high iron intakes, iron supplements may compromise zinc status if the diet is low in zinc. The RDA is 12 mg/day for pregnant women ages 18 and younger and 11 mg/day for pregnant women 19 years of age and older.[44] The zinc in red meat is more absorbable than from other sources; a 3-oz serving of lean ground beef provides about 2 mg of zinc.

Iron Pregnancy increases the risk of iron deficiency anemia. Iron needs are high during pregnancy to provide for the synthesis of hemoglobin and other iron-containing proteins in both maternal and fetal tissues. Many women start pregnancy with diminished iron stores and quickly become iron deficient. This occurs even though iron absorption is increased during pregnancy and iron losses are decreased due to the cessation of menstruation. Iron deficiency anemia during pregnancy has been associated with an increased risk of low birth weight and preterm delivery.[45] The fetus draws iron from the mother to ensure adequate fetal hemoglobin production, mostly during the last trimester. Babies born prematurely may not have had time to accumulate sufficient iron, but babies born at term usually have adequate iron stores even if the mother is deficient.

The RDA for iron during pregnancy is 27 mg/day compared with 18 mg/day for nonpregnant women.[44] It takes an exceptionally well-planned diet to meet iron needs during pregnancy. Red meats, leafy green vegetables, and fortified cereals are good sources of iron. Foods that enhance iron absorption, such as citrus fruit and meat, should also be included in the diet. Iron supplements are typically recommended during the second and third trimesters of pregnancy.

Meeting Nutrient Needs with Food and Supplements

The energy and nutrient needs of pregnancy can be met by following the recommendations of the Dietary Guidelines and MyPlate for pregnancy (**Figure 14.12**). Additional grains, vegetables, and fruits provide energy, protein, folate, vitamin C, and fiber, particularly if whole grains are chosen. An extra serving of dairy provides energy, protein, calcium, vitamin D, and riboflavin. Additional lean meat provides energy, protein, vitamin B_6, vitamin B_{12}, iron,



	Grains Make half your grains whole	Vegetables Vary your veggies	Fruits Focus on fruits	Dairy Get your calcium-rich foods	Protein Choose lean with protein
1st Trimester	7 ounces	3 cups	2 cups	3 cups	6 ounces
2nd Trimester	8 ounces	3 cups	2 cups	3 cups	6 1/2 ounces
3rd Trimester	9 ounces	3 1/2 cups	2 cups	3 cups	6 1/2 ounces

choosemyplate.gov

FIGURE 14.12 MyPlate for pregnancy
This MyPlate Daily Food Plan is for a 26-year-old pregnant woman who is 5 feet 4 inches tall, gets 30 to 60 minutes of exercise a day, and weighed 125 lb before she became pregnant. Energy needs are not increased during the first trimester, so the recommended amounts from each group for the first trimester are the same as for a nonpregnant woman.

and zinc. For example, adding a snack such as a turkey sandwich on whole-grain bread, an apple, and a glass of low-fat milk will provide all the extra energy and nutrients needed daily for a healthy pregnancy (see **Critical Thinking: Nutrient Needs for a Successful Pregnancy**).

Dietary Supplements Even when a healthy diet based on a Daily Food Plan is consumed, it is difficult to meet all vitamin and mineral needs during pregnancy. Generally, supplements of folic acid are recommended before and during pregnancy, and iron supplements are recommended during the second and third trimesters.[2] A multivitamin and mineral supplement may also be necessary in those whose food choices are limited, such as vegetarians, or in those whose needs are very high, such as pregnant teenagers. A prenatal supplement, however, must be taken in conjunction with, not in place of, a carefully planned diet. This is because these supplements do not contain enough of all the micronutrients needed for pregnancy and do not provide the protein needed for tissue synthesis or the carbohydrates required for energy. They lack fiber, which helps prevent constipation, and they do not contain the fluid needed for expanding blood volume and maintaining normal bowel function. They also don't contain

CRITICAL THINKING

Nutrient Needs for a Successful Pregnancy

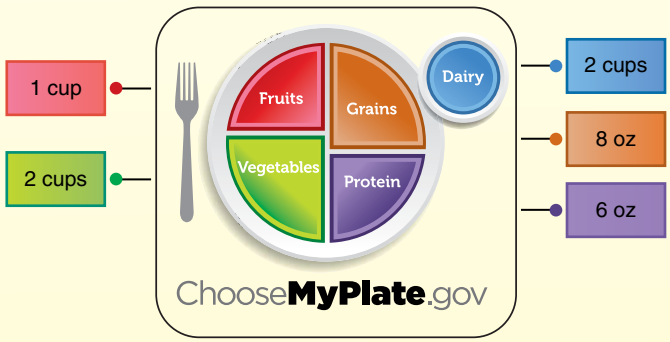
Mark Burstyn/Masterfile

Tina is a sedentary 26-year-old at the end of her fourth month of pregnancy. She is 5 ft 4 in. tall and weighed 125 lb at the start of her pregnancy. Tina's typical diet provides enough energy for a nonpregnant woman, but now that she is in her second trimester, she needs additional calories and nutrients.

Complete the table below to compare Tina's current energy and protein intake to the amounts recommended during her second and third trimester.

	ENERGY (kcal)	PROTEIN (g)	IRON (mg)	FIBER (g)
Tina's typical diet	2000	99	13.5	20
Second trimester recommendations			27	28
Third trimester recommendations			27	28

The illustration below shows the amounts of food from each food group that Tina currently consumes.



Compare Tina's current intake to the MyPlate recommendations for the second trimester of pregnancy as shown in Figure 14.12. How much from which groups does she need to add to her diet?

Tina is taking a prenatal supplement but is curious about whether her diet alone can meet her nutrient needs.

iProfile Use iProfile to find good food sources of heme and nonheme iron.

CRITICAL THINKING QUESTIONS

- **Plan snacks that provide the additional food group servings that Tina should be eating. Do these snacks provide the additional calories and fiber recommended in the second trimester?**
- **What foods could Tina add to her diet to increase her iron intake by 13.5 mg/day? How many calories and how much protein would these add?**
- **Considering the foods you suggested to increase her iron intake, do you think it is reasonable for Tina to meet the recommended iron intake for pregnancy from her diet alone? Why or why not?**

Andy Washnik

Supplement Facts

Serving Size 1 Tablet
Servings Per Container 60

Amount Per 1 Tablet	% Daily Value*
Vitamin A (as beta carotene) 5000 IU	63%
Vitamin C (as ascorbic acid) 85 mg	100%
Vitamin D (as cholecalciferol) 400 IU	67%
Vitamin E (as d-alpha tocopheryl) acetate (Covitol™) 22 IU	67%
Vitamin K 90 mcg	100%
Thiamin 1.4 mg	100%
Riboflavin 1.6 mg	100%
Niacin (as niacinamide) 17 mg	100%
Vitamin B_6 (as pyridoxine HCl) 2.6 mg	137%
Folic acid 1000 mcg	167%
Vitamin B_{12} (as cyanocobalamin) 2.6 mg	100%
Pantothenic Acid (as as d-calcium pantothenate) 6 mg	100%
Iron (as iron fumarate) 27 mg	100%
Iodine (kelp) 220 mcg	100%
Zinc (as monomethionine & gluconate) 11mg	100%
Selenium (as sodium selenate) 60 mcg	100%
Copper (as copper sulfate) 1000 mcg	100%
Calcium (as calcium carbonate) 200 mg	20%

*** Daily Values based on RDAs for pregnant women ages 19-50**

Other ingredients: stearic acid, vegetable stearate, silicon dioxide, croscarmellose sodium, microcrystalline cellulose, natural coating (contains hydroxypropyl methylcellulose, titanium dioxide, riboflavin, polyethylene glycol and polysorbate)

FIGURE 14.13 Prenatal supplements
Taking a multivitamin/mineral supplement during pregnancy can be beneficial if the recommended dosage is not exceeded and the supplement does not take the place of a carefully planned diet. The supplement shown here does not provide any magnesium and contains only 200 mg of calcium, 20% of the recommended intake for a pregnant woman 19 to 50 years of age.

THINK CRITICALLY

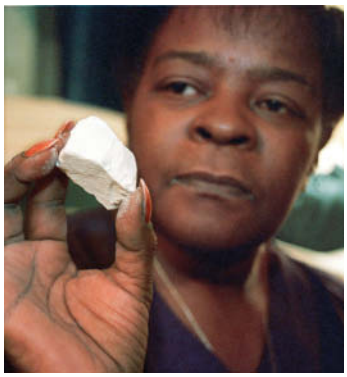
Why don't supplement manufacturers make a prenatal multivitamin/mineral supplement that meets recommendations for magnesium and calcium?

other food components such as the phytochemicals supplied by a diet rich in whole grains, fruits, and vegetables (Figure 14.13).

Food Cravings and Aversions Most women change their diets during pregnancy. Some changes are made in an effort to improve nutrition to ensure a healthy infant, but others are based on cravings, aversions, or cultural or family traditions. Foods that are commonly craved include fruit and fruit juices, sweets, candy (particularly chocolate), and dairy products. Common aversions include coffee and other caffeinated drinks, alcohol, meat, fish, poultry, eggs, highly seasoned foods, or fried foods. It has been suggested that hormonal or physiological changes during pregnancy—in particular, changes in taste and smell—may be the cause of such cravings and aversions.

Usually the food cravings of pregnant women can be indulged within reason with no harmful effects. But abnormal cravings leading to consumption of nonfood substances can have serious consequences. **Pica** is the persistent ingestion of nonfood substances having little or no nutritional value (see Focus on Eating Disorders).[46] Pica has been described since antiquity, but its cause is still a mystery. It was once thought that pica was an attempt to meet micronutrient needs. It is now believed that it may be more related to cultural factors than the need for micronutrients. It is more common in African American women and in those with a family or personal history of the practice (Figure 14.14).[47] Women with pica commonly consume clay, soil, laundry starch, ice and freezer frost, talcum powder, cornstarch, and ashes. Consuming large amounts of these can reduce the intake of nutrient-dense foods, reduce nutrient absorption from food, increase the risk of consuming toxins and harmful microorganisms, and even cause intestinal obstructions. Complications of pica include iron deficiency anemia, lead poisoning, and parasitic infections.[47] Anemia and hypertensive disorders of pregnancy are more common in mothers who practice pica, but it is not clear if pica is a result of these conditions or a cause. In newborns, anemia and low birth weight are often related to pica in the mother.

pica A persistent ingestion of nonnutritive, nonfood items.



© Michael DiBari, Jr./AP Wide World Photos

FIGURE 14.14 Pica and cultural beliefs
This African American woman in Georgia is eating a white clay called kaolin, which some women crave during pregnancy. Eating kaolin is also a traditional remedy for morning sickness. This example of pica may be related to cultural beliefs and traditions.

14.3 Factors That Increase the Risks of Pregnancy

LEARNING OBJECTIVES

- Explain how maternal nutritional status before and during pregnancy can affect the health of the offspring.
- Discuss the effects of maternal age and health status on pregnancy outcome.
- Discuss how income level affects the risks of pregnancy.
- Describe the effects of maternal drug and alcohol use on pregnancy outcome.

There are many reasons for poor pregnancy outcome. Malnutrition is a factor in some women. Others are at increased risk because of their age and preexisting health problems or socioeconomic factors such as limited access to health care, lack of a supportive home environment, or insufficient resources to acquire nutritious foods (Table 14.3). Some women and babies are at risk because they are exposed to harmful substances from their diet or environment.

TABLE 14.3 Factors That Increase Pregnancy Risks

Maternal factor	Maternal risk	Infant/fetal risk
Prepregnancy BMI < 18.5 or gaining too little weight during pregnancy	Anemia, premature rupture of the membranes, hemorrhage after delivery	Low birth weight, preterm birth
Prepregnancy BMI ≥ 30 or gaining too much weight during pregnancy	Hypertensive disorders of pregnancy, gestational diabetes, difficult delivery, cesarean section	Large-for-gestational-age, low Apgar scores (a score used to assess the health of a baby in the first minutes after birth), and neural tube defects
Malnutrition	Decreased ability to conceive, anemia	Fetal growth retardation, low birth weight, birth defects, preterm birth, spontaneous abortion, stillbirth, increased risk of chronic disease later in life
Phenylketonuria	High blood levels of phenylketones	Brain damage leading to intellectual disability if low phenylalanine diet is not carefully followed by mother
Hypertension	Stroke, heart attack, premature separation of the placenta from the uterine wall	Low birth weight, fetal death
Diabetes	Difficulty adjusting insulin dose, preeclampsia, cesarean section	Large-for-gestational-age, congenital abnormalities, fetal death
Frequent pregnancies: three or more during a two-year period	Malnutrition	Low birth weight, preterm birth
History of poor obstetric or fetal outcome	Recurrence of problem in subsequent pregnancy	Birth defects, death
Age:		
Younger than 20	Malnutrition, hypertensive disorders of pregnancy	Low birth weight
Older than 35	Hypertensive disorders of pregnancy, gestational diabetes	Down syndrome and other chromosomal abnormalities
Alcohol consumption	Poor nutritional status	Fetal alcohol spectrum disorders, including fetal alcohol syndrome
Cigarette smoking	Lung cancer and other lung diseases, miscarriage	Low birth weight, stillbirth, preterm birth, sudden infant death syndrome, respiratory problems
Illicit drug use	Malnutrition, miscarriage, premature labor and delivery	Perinatal drug addiction, intrauterine growth retardation, low birth weight, preterm birth, birth defects, sudden infant death syndrome

Maternal Nutritional Status

Proper nutrition is important before pregnancy to support conception and maximize the likelihood of a healthy pregnancy. At any time during pregnancy, maternal malnutrition due to a deficiency or excess of energy or individual nutrients can affect pregnancy outcome.

Nutritional Status Before Pregnancy A woman's nutritional status before she becomes pregnant may affect her ability to conceive and successfully complete a pregnancy. Starvation diets, anorexia nervosa, and excessive exercise, such as marathon running, can reduce body fat and affect hormone levels. If hormone levels are too low, ovulation does not occur and conception is not possible. Too much body fat can also reduce fertility by altering hormone levels. Deficiencies or excesses of nutrients can affect pregnancy outcome. For instance, a deficiency of folate or an excess of vitamin A early in pregnancy can cause birth defects.

Nutritional status can be affected by some birth control methods and these can therefore have an impact on a subsequent pregnancy. For example, oral contraceptives are associated with reduced blood levels of vitamin B_{12}.[48] If conception occurs soon after oral contraceptive use stops, these levels will not have had time to return to normal before pregnancy begins.

Malnutrition During Pregnancy Maternal malnutrition can cause fetal growth retardation, low infant birth weight, birth defects, premature birth, spontaneous abortion, and stillbirth. Maternal nutritional status during pregnancy can also affect the long-term health of the offspring.

Immediate Effects of Maternal Malnutrition The immediate effect of maternal malnutrition depends on how severe the nutrient deficiency or excess is and when during the pregnancy it occurs. In general, poor nutrition early in pregnancy affects embryonic development and the potential of the embryo to survive, and poor nutrition in the latter part of pregnancy affects fetal growth. Insufficient energy intake during early pregnancy is not likely to interfere with fetal growth because the energy demands of the embryo are small. However, if the embryo does not receive adequate amounts of the nutrients needed for cell division and differentiation, such as folate and vitamin A, malformations or death can result. Inadequate folate intake in the first few weeks of pregnancy may affect neural tube development.[33] Maternal nutrient excesses can also be harmful. For example, too much vitamin A can cause kidney problems and central nervous system abnormalities in the offspring even when maternal intake is not extremely high. High intakes early in pregnancy are the most damaging. A UL of 3000 μg/day has been established for pregnant women ages 19 to 50 years.[44] Supplements consumed during pregnancy should therefore contain the vitamin A precursor β-carotene, which is not damaging to the fetus.

Malnutrition is most likely to cause developmental defects (malformations) during the first trimester. After the first trimester, nutrient deficiencies or excesses are less likely to cause malformations because most organs and structures have already formed. However, undernutrition in the mother after the first trimester can interfere with fetal growth. Even a mild energy restriction during the last trimester, when the fetus is growing rapidly, can affect birth weight. Malnutrition also interferes with the growth and function of the placenta. A poorly developed placenta cannot deliver sufficient nutrients to the fetus, and the result is a small infant who may also have other developmental abnormalities.

Long-Term Effects of Maternal Malnutrition It has been proposed that problems in maternal nutrition can cause adaptations that change fetal structure, physiology, and metabolism and can affect the child's risk of developing chronic diseases later in life. The process that allows nutrition early in development to trigger permanent responses later in life is referred to as *nutritional programming*. There is strong evidence that maternal under- and overnutrition during pregnancy can lead to alterations in metabolism and body composition in the offspring later in life. Nutritional programming that occurs before birth is now thought to be important in the development of obesity, type 2 diabetes, and cardiovascular disease.[49,50] Evidence for this is seen in the babies born to women who were calorie deprived during World War II. These children

were more likely than others to develop obesity, diabetes, heart disease, and other chronic diseases as adults.[51]

Maternal Health Status

The general health as well as nutritional status of the mother affects the outcome of pregnancy. Women who begin pregnancy with chronic diseases such as hypertension and diabetes must manage their health carefully to ensure a healthy pregnancy. The effect of hypertension depends on when it develops and how severe it is. As in nonpregnant individuals, high blood pressure in pregnant women increases the risk of stroke and heart attack, but in pregnancy it also increases the risk of low birth weight and premature separation of the placenta from the wall of the uterus, resulting in fetal death.

Women with diabetes must carefully manage diet and medication to ensure that glucose levels stay in the normal range throughout pregnancy. Uncontrolled diabetes early in pregnancy increases the risk of birth defects. When normal blood glucose is maintained throughout pregnancy, the risk of complications is greatly reduced. The need for insulin increases during the second and third trimesters, so women with preexisting diabetes may need to adjust their medication dosage. When maternal blood glucose is elevated, it provides extra calories to the growing fetus, resulting in large-for-gestational-age newborns who are at increased risk.

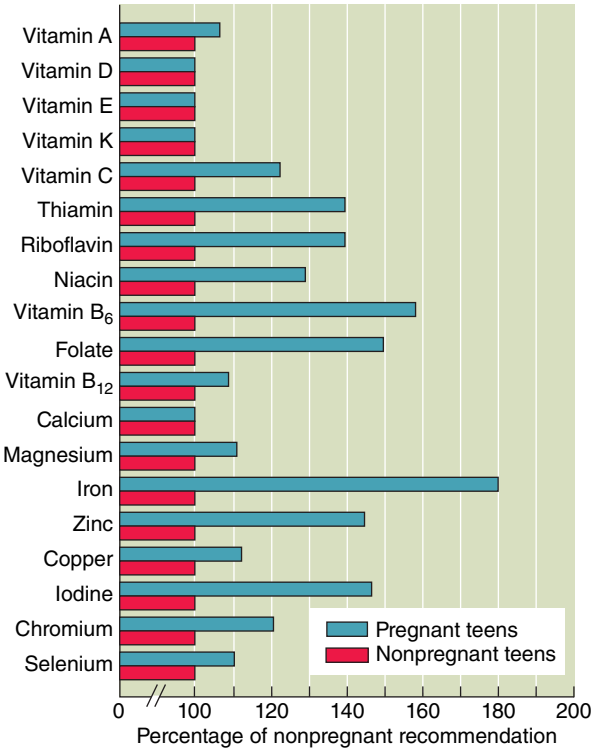


FIGURE 14.15 Nutrient needs of pregnant teens
Because the nutrient needs of pregnant teens are different from those of pregnant adults, the DRIs include a special set of recommendations for this age group. This graph compares the micronutrient needs of 14- to 18-year-old pregnant and nonpregnant teens.

Reproductive History Frequent pregnancies, with little time between, increase the risk of poor pregnancy outcomes. One reason is that the mother may not have replenished nutrient stores depleted in the first pregnancy when she becomes pregnant again. An interval of less than 18 months increases the risk of delivering a full-term but small-for-gestational-age infant. An interval of only 3 months has been shown to increase the risk of a preterm or small-for-gestational-age infant as well as neonatal death.[52] Women with a history of poor pregnancy outcome are also at increased risk. For example, a woman who has had a number of miscarriages is more likely to have another, and a woman who has had one child with a birth defect has an increased risk for defects in subsequent children.

The Pregnant Teenager Pregnancy places a stress on the body at any age, but this is compounded when the mother herself is still growing. Although the rate of teen pregnancy has been decreasing, from 62 babies per 1000 teens in 1991 to about 27 per 1000 in 2013, it remains a major public health problem.[53] Pregnant teens are at greater risk of developing hypertensive disorders of pregnancy and are more likely to deliver preterm and low-birth-weight babies. To produce a healthy baby, a pregnant teenager needs early medical intervention and nutritional counseling.

Adolescent girls continue to grow and mature physically for about four to seven years after menstruation begins. Therefore the diet of a pregnant teen must provide both for her growth and that of her baby. Even teenagers who deliver normal-birth-weight infants may stop growing themselves.[54] Because the nutrient needs of a pregnant teen may be higher than those of a pregnant adult, the DRIs include a special set of nutrient recommendations for pregnant teens (Figure 14.15). Consuming a diet that meets these needs can be challenging. Even nonpregnant teens often fall short of meeting their nutrient needs. Nutrients that are commonly low in the diets of pregnant teens are calcium, iron, zinc, magnesium, vitamin D, folate, and vitamin B_6.[29,33]

THINK CRITICALLY

Why are the micronutrient needs of a pregnant teen higher than those of a 25-year-old pregnant woman of the same weight?

The Older Mother The nutritional requirements for older women during pregnancy are no different than those for women in their twenties, but pregnancy after the age of 35 does carry additional risks because older women are more likely to start pregnancy with medical conditions

such as cardiovascular disease, kidney disease, obesity, and diabetes. These preexisting conditions increase the risks associated with pregnancy. For example, a woman who has preexisting high blood pressure is at increased risk for having a low-birth-weight baby, and a woman who has diabetes is more likely to have a baby who is large for gestational age. Older women are also more likely to develop gestational diabetes, hypertensive disorders of pregnancy, and other complications. Older women have a higher incidence of low-birth-weight babies, preterm birth, stillbirth, and perinatal death; however, the actual rate of stillbirth/neonatal death is still very low.[55] Greater maternal age also increases the risk of having a baby with chromosomal abnormalities, especially **Down syndrome** (Figure 14.16). Today, careful medical monitoring throughout pregnancy is reducing the risks to older mothers and their babies.

Down syndrome A disorder caused by extra genetic material that results in cognitive disabilities, distinctive facial characteristics, and other abnormalities.

Socioeconomic Factors

One of the greatest risk factors for poor pregnancy outcome is poverty, which limits access to food, education, and health care.[57] Low-income women are unlikely to receive medical care until late in pregnancy and consequently have a high incidence of low-birth-weight and preterm infants. One federally funded program that addresses the nutritional needs of pregnant women is the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC). WIC participation has been shown to reduce health-care costs by providing preventive care to low-income pregnant women through nutrition education and food vouchers.[58] This program provides services to pregnant women, to nonlactating women for 6 months after birth, to lactating women for 12 months after birth, and to infants and children up to 5 years of age.

Exposure to Toxic Substances

During development, cells are particularly vulnerable to damage because they are dividing rapidly, differentiating, and moving to form organs and other structures. Anything that interferes with this development can cause a baby to be born too soon or too small or can result in birth defects. A **teratogen** is any chemical, biological, or physical agent that can cause birth defects. Even some vitamins have been found to be teratogens. The placenta prevents some teratogens from passing from the mother's blood to the embryonic or fetal blood, but it cannot prevent the passage of all hazardous substances.

teratogen A substance that can cause birth defects.

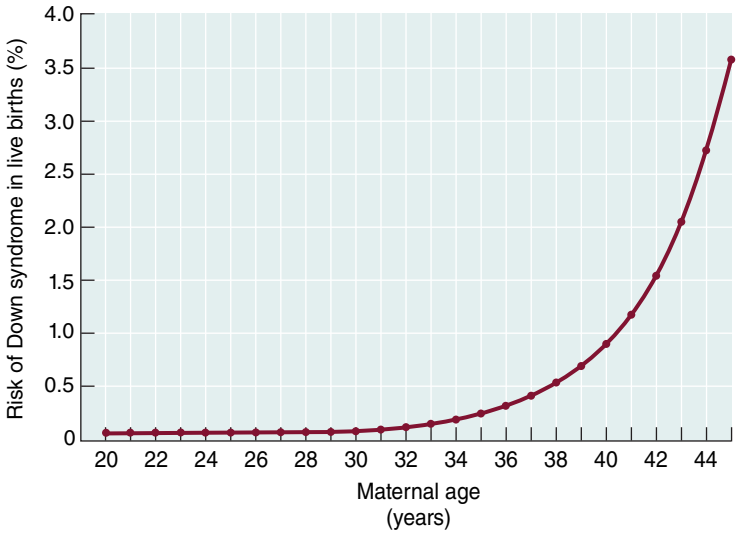


FIGURE 14.16 Incidence of Down syndrome
Down syndrome is caused by a defect during egg or sperm formation that results in an extra copy of chromosome 21. It causes developmental and cognitive delays, distinctive facial characteristics, and other health problems. The incidence of Down syndrome rises with maternal age of 35 years and older. However, over 80% of Down syndrome births are to women under the age of 35, as younger women have more babies overall.[56]

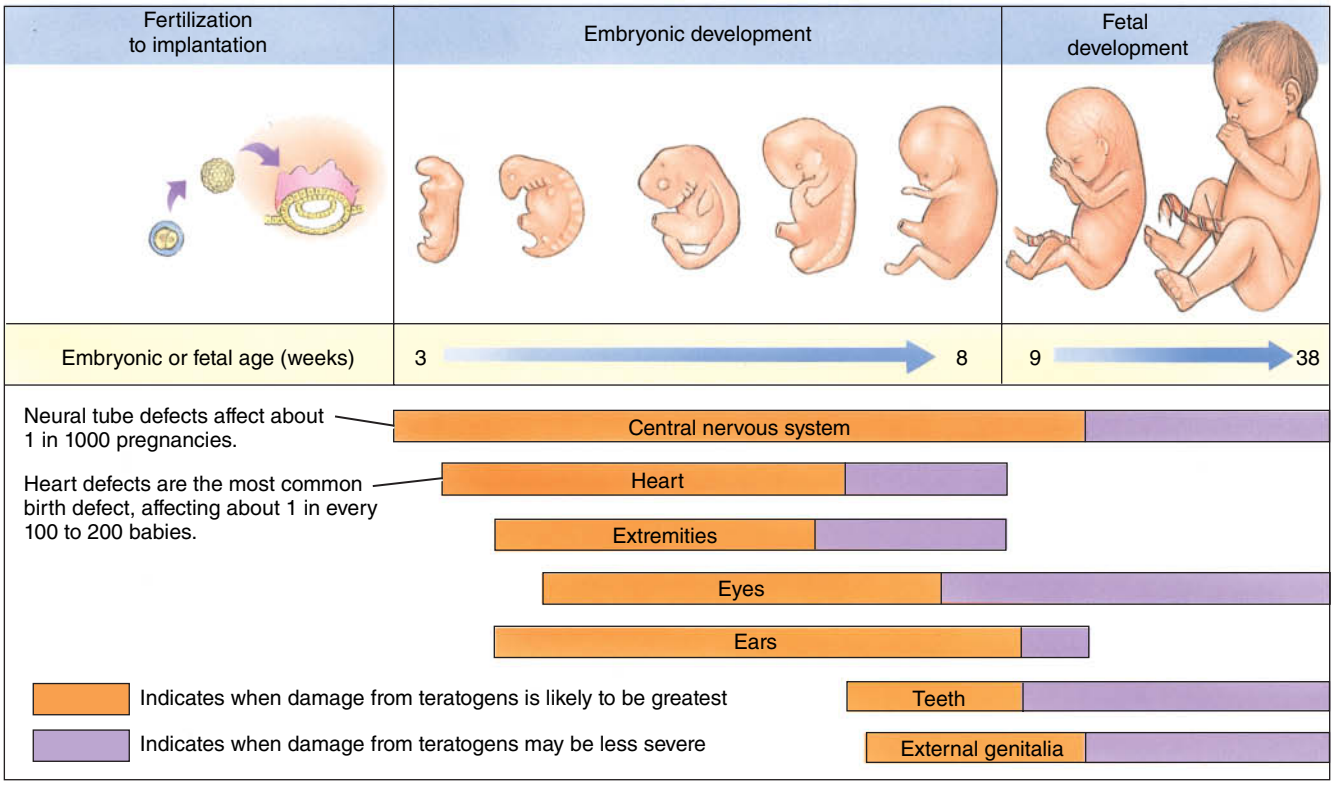


FIGURE 14.17 Critical periods of development
The critical periods of development are different for various body systems.[59] Heart defects are the most common birth defect.

Each organ system develops at a different rate and time, so each has a critical period when exposure to a teratogen or other insult can disrupt development and cause irreversible damage (Figure 14.17). If the damage is severe, it may result in a miscarriage. Because the majority of cell differentiation occurs during the embryonic period, this is the time when exposure to teratogens can do the most damage, but vital body organs can still be affected during the fetal period. As discussed previously, deficiencies or excesses of energy or nutrients during pregnancy can affect the health of the embryo and fetus and cause developmental errors. Other substances present in the environment, consumed in the diet, or taken as medications or recreational drugs can also act as teratogens.

Environmental Toxins In a pregnant woman, exposure to environmental toxins—such as cleaning solvents, lead, mercury, some insecticides, and paint—can affect her developing child. Therefore, pregnant women need to be aware of the potential toxins in their food, water, and environment.

Mercury in Fish Fish has both benefits and risks for pregnant women. It is a source of lean protein for tissue growth and of omega-3 fatty acids and iodine needed for brain development, but if it is contaminated with mercury, consumption during pregnancy can cause developmental delays and brain damage. Pregnant women should consume 8 to 12 oz/week of a variety of types of fish and shellfish. Exposure to mercury from fish can be controlled by avoiding varieties that are high in mercury and limiting intake of fish that contain lower amounts of mercury (Table 14.4 and Chapter 17).[60,61]

Caffeine and Herbs Caffeine-containing beverages like coffee are a part of our typical diet, but the ability to metabolize caffeine is reduced during pregnancy.[2] Women who are pregnant or trying to become pregnant are therefore advised to limit caffeine consumption to less than 200 mg/day, the amount in 1 or 2 cups of coffee or about two or three 20-oz caffeinated soft drinks.[63] This amount and higher amounts of caffeine have not been found to increase the risk of birth defects, miscarriage, or low birth weight.[64] Herbal teas are also popular beverages. Some are

TABLE 14.4 Food Safety During Pregnancy[61,62]

Eat 8 to 12 oz (two or three servings) of a variety of fish and shellfish weekly.
Choose fish low in mercury, such as salmon, shrimp, pollock, tuna (light canned), tilapia, catfish, and cod.
Avoid the four types of fish that are highest in mercury (tilefish, shark, swordfish, and king mackerel) and limit white (albacore) tuna to 6 oz/week.
Pay attention to fish advisories when eating fish caught from streams, rivers, and lakes. If advice is not available, eat up to 6 oz/week, but don't consume any other fish during that week.
Don't drink raw (unpasteurized) milk or consume products made with unpasteurized milk, such as certain Mexican-style soft cheeses.
Don't eat refrigerated smoked fish, cold deli salads, or refrigerated pâtés or meat spreads.
Don't eat hot dogs and luncheon meats unless they have been reheated to steaming hot.
Don't eat raw or undercooked meat, poultry, fish, shellfish, or eggs.
Don't eat unwashed fruits and vegetables, raw sprouts, or unpasteurized juice.

consumed to treat the discomforts of pregnancy. For example, ginger and raspberry leaves are often used to treat morning sickness. However, because there is not a great deal of research on herbal teas and other herbal products, pregnant women should avoid them until they are shown to be safe for use during pregnancy.

Food-Borne Illness The immune system is weakened during pregnancy, increasing susceptibility to and severity of certain food-borne illnesses. *Listeria* infection is 18 times more likely during pregnancy and is associated with an increased risk of miscarriage and stillbirth; the infection can be transmitted to the fetus, causing meningitis and serious blood infections.[65] About one-third of fetuses with *Listeria* infection do not survive.[66] The bacteria are commonly found in unpasteurized milk, soft cheeses, and uncooked hot dogs and lunchmeats (see Chapter 17).

Toxoplasmosis is an infection caused by a parasite. If a pregnant woman becomes infected, the infection can be passed to her unborn baby. Infected babies may develop vision and hearing loss, intellectual disability, and/or seizures, and some die within a few days of birth. The toxoplasmosis parasite is found in cat feces, soil, and undercooked infected meat. Pregnant women should follow the guidelines in Table 14.4 and the safe food-handling recommendations discussed in Chapter 17.

How Alcohol Affects Pregnancy Outcome Alcohol consumption during pregnancy is one of the leading causes of preventable birth defects (see Focus on Alcohol). Alcohol is a teratogen that is particularly damaging to the developing central nervous system.[67] It also indirectly affects fetal growth and development because it is a toxin that reduces blood flow to the placenta, thereby decreasing the delivery of oxygen and nutrients to the fetus. The use of alcohol can also impair maternal nutritional status, further increasing the risk to the embryo or fetus.

Prenatal exposure to alcohol can cause a spectrum of disorders depending on the dose, timing, and duration of the exposure. One of the most severe outcomes of drinking alcohol during pregnancy is a baby with **fetal alcohol syndrome (FAS)**. FAS is characterized by facial deformities, growth retardation, and permanent brain damage (Figure 14.18). Newborns with the syndrome may be shaky and irritable, with poor muscle tone and alcohol withdrawal symptoms. Other problems include heart and urinary tract defects, impaired vision and hearing, and delayed language development. Intellectual disability is the most common and most serious effect. Not all babies who are exposed to alcohol while in the uterus have FAS. The term **fetal alcohol spectrum disorders (FASDs)** is used to refer to all the physical or behavioral disorders or conditions and functional or mental impairments linked to prenatal alcohol exposure.[68] As many as 2 to 5% of young school children in the United States are affected by FASDs.[69]

fetal alcohol syndrome (FAS) A characteristic group of physical and mental abnormalities in an infant resulting from maternal alcohol consumption during pregnancy.

fetal alcohol spectrum disorders (FASDs) A continuum of permanent birth defects in a child due to maternal alcohol consumption during pregnancy.

Because alcohol consumption in each trimester has been associated with abnormalities and because there is no level of alcohol consumption that is known to be safe, complete abstinence from alcohol is recommended during pregnancy. Warning labels that appear on containers of beer, wine, and hard liquor state that "According to the Surgeon General, women should not drink alcoholic beverages during pregnancy because of the risk of birth defects."

© 2012 Susan Astley PhD, University of Washington

FIGURE 14.18 Fetal alcohol syndrome
Facial characteristics shared by children with fetal alcohol syndrome include a low nasal bridge, a short nose, distinct eyelids, and a thin upper lip.

Cigarette Smoke If a woman smokes cigarettes during pregnancy, her baby will be affected before birth and throughout life. The carbon monoxide in tobacco smoke binds to hemoglobin, reducing oxygen delivery to fetal tissues. The nicotine absorbed from cigarette smoke is a teratogen that can affect brain development.[70,71] Nicotine also constricts arteries and limits blood flow, reducing both oxygen and nutrient delivery to the fetus.[72] Cigarette smoking during pregnancy reduces birth weight and increases the risk of preterm delivery, stillbirth, neurobehavioral problems, and early death.[70] Even exposure to cigarette smoke from the environment has been found to increase the risk of low birth weight. The risks of **sudden infant death syndrome (SIDS)**, or **crib death**, and respiratory problems are also increased in children exposed to cigarette smoke both in the uterus and after birth.[73] The effects of maternal smoking follow children throughout life; they are more likely to have frequent colds and develop lung problems later in life.[74]

sudden infant death syndrome (SIDS) or **crib death** The unexplained death of an infant, usually during sleep.

Legal and Illicit Drug Use The use of drugs—whether over-the-counter, prescribed, or illicit—can also affect both fertility and pregnancy outcome. For example, the acne medications Accutane and Retin-A, which are derivatives of vitamin A, can cause birth defects if used during pregnancy. A woman who is considering pregnancy should discuss her plans with her physician in order to determine the risks associated with any medication she is taking.

Abuse of illegal substances during pregnancy is a national health issue. It is estimated that about 4.4% of pregnant women use illicit drugs.[75] The risk to the infant depends on the drug. Marijuana and cocaine can cross the placenta and enter the fetal blood. Prenatal marijuana exposure may cause subtle abnormalities in infant neurobehavior, such as increased irritability and muscle tremors, but it has not been shown to affect fetal growth or cause birth defects.[75] Cocaine use creates problems for both the mother and the infant before, during, and after delivery.[76] Cocaine is a teratogen that interferes with nervous system development and may cause permanent changes in brain structure and function.[75] Cocaine also constricts blood vessels, thereby reducing the delivery of oxygen and nutrients to the fetus. Cocaine use during pregnancy is

associated with an increased risk of miscarriage, fetal growth retardation, premature labor and delivery, low birth weight, and birth defects.[77] Exposure to cocaine and other illegal drugs before birth has also been shown to affect infant behavior and influence learning and attention span during childhood.[75]

14.4 Lactation

LEARNING OBJECTIVES

- Explain the relationship between suckling and milk production and letdown.
- Compare the nutritional needs of lactating women with those of nonpregnant, nonlactating women of childbearing age.

The nutrient requirements of pregnancy include those needed to prepare for lactation. After childbirth, the breast-feeding mother's nutrient intake must support milk production and can influence the nutrient composition of her milk.

Milk Production and Letdown

Lactation involves both the synthesis of the milk components, such as milk proteins, lactose, and milk lipids, and the movement of these milk components through the milk ducts to the nipple. Throughout pregnancy, hormones prepare the breasts for lactation by stimulating the enlargement and development of the milk ducts and the milk-producing glands, called *alveoli* (Figure 14.19). During the first few days after childbirth, the breasts produce and secrete a small amount of a clear yellow fluid called **colostrum**. Colostrum is immature milk. It is rich in protein, including immune factors that help protect the newborn from disease. Within about a week of childbirth, there is a rapid increase in milk secretion, and its composition changes from colostrum to that of mature milk.

colostrum The first milk, which is secreted in late pregnancy and up to a week after birth. It is rich in protein and immune factors.

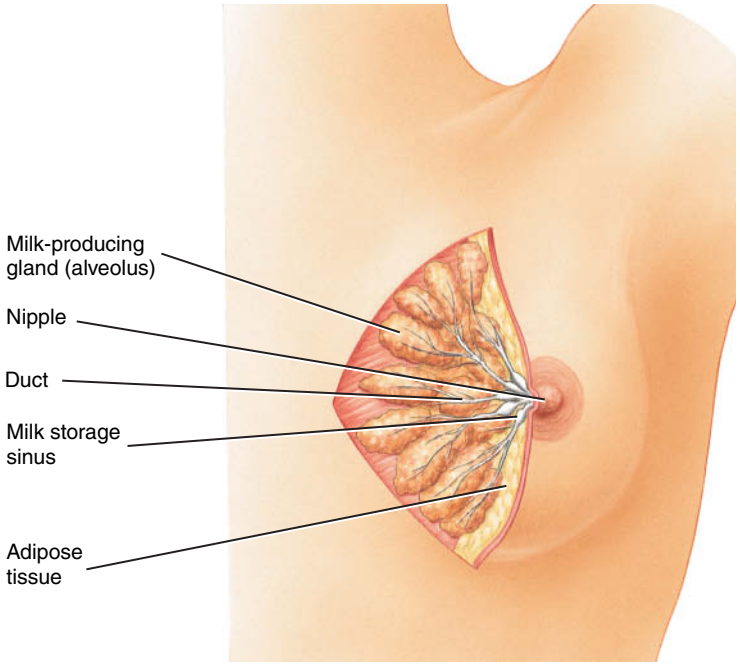


FIGURE 14.19 Anatomy of lactation
During lactation, milk travels from the milk-producing glands through the ducts to milk storage sinuses and then to the nipple.

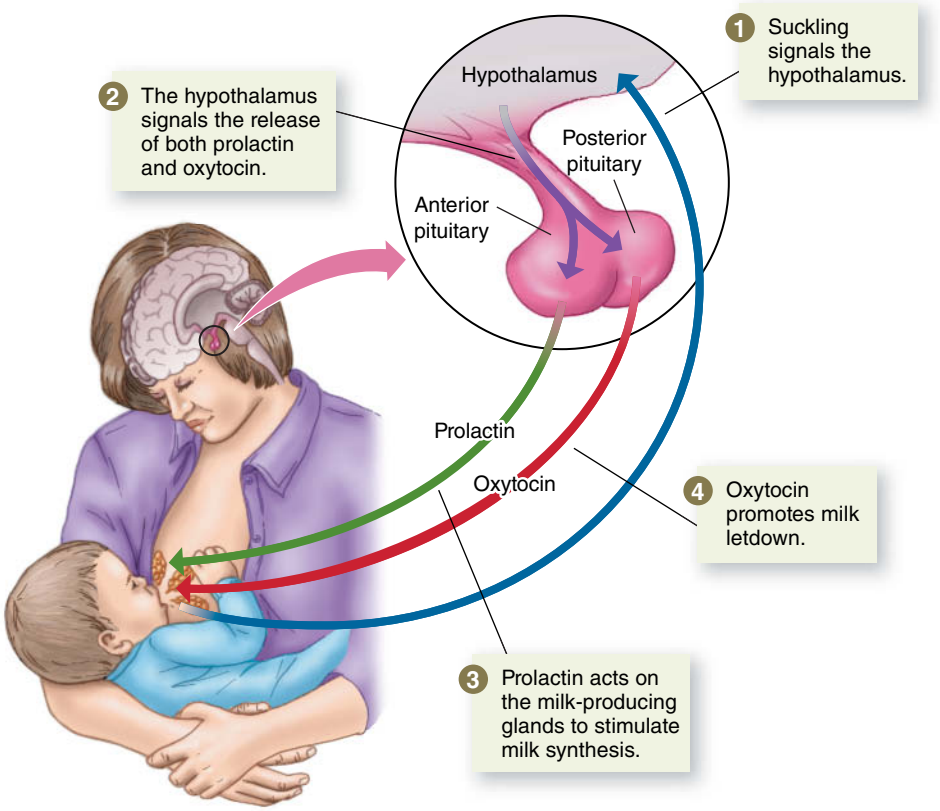


FIGURE 14.20 Hormones of lactation
When the infant suckles, nerve receptors in the nipple send signals to the hypothalamus that trigger the release of prolactin and oxytocin.

prolactin A hormone secreted by the anterior pituitary that acts on the milk-producing glands in the breast to stimulate and sustain milk production.

letdown A hormonal reflex triggered by an infant's suckling that causes milk to be released from the milk glands and flow through the duct system to the nipple.

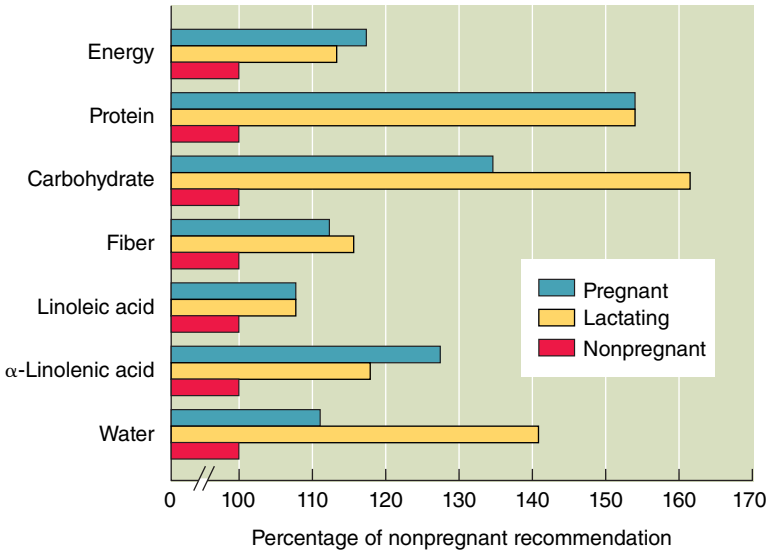
oxytocin A hormone produced by the posterior pituitary gland that acts on the uterus to cause uterine contractions and on the breast to cause the movement of milk into the secretory ducts that lead to the nipple.

Milk production and release are triggered by hormones that are secreted in response to the suckling of the infant (Figure 14.20). The pituitary hormone **prolactin** stimulates milk production; the more the infant suckles, the more milk is produced. The release of milk from the milk-producing glands and its movement through the ducts and storage sinuses is referred to as **letdown**. The letdown of milk is caused by **oxytocin**, another hormone produced by the pituitary gland that is secreted in response to the suckling of the infant. As nursing becomes more automatic, oxytocin secretion and the letdown of milk may occur in response to the sight or sound of an infant. It can be inhibited by nervous tension, fatigue, or embarrassment. The letdown response is essential for successful breast-feeding and makes suckling easier for the child. If letdown is slow, the child can become frustrated and difficult to feed.

How Lactation Affects Maternal Nutrient Needs

The need for many nutrients is even greater during lactation than during pregnancy. This is because the mother is still providing for all the energy and nutrient needs of the infant, who is growing faster and is more active than the fetus. Meeting the needs of lactation requires a varied, nutrient-dense diet. Most lactating women can meet all their needs without supplements.

Energy and Macronutrient Needs During the first six months of lactation, approximately 600 to 900 mL (2.5 to 3.8 cups) of milk is produced daily, depending on how much the infant consumes. Human milk contains about 160 kcal/cup (about 240 mL), so providing an infant with 3 cups of milk requires the mother to expend approximately 500 kcal. Much of this must come from the diet, but some can come from mobilization of maternal fat stores, which increase during pregnancy. The EER for lactation is estimated by adding the total energy expenditure of nonlactating women and the energy in milk and then subtracting the energy supplied by



THINK CRITICALLY

Why are water needs higher during lactation than during pregnancy?

FIGURE 14.21 Energy and macronutrient needs during lactation
This graph compares the energy and macronutrient recommendations for 25-year-old nonpregnant women and 25-year-old women during the third trimester of pregnancy and the first six months of lactation.

maternal fat stores.[23] This is equal to an additional 330 kcal/day during the first six months of lactation, and 400 kcal/day during the second six months. To ensure adequate protein for milk production, the RDA for lactation is 25 g/day higher than for nonlactating women. The recommended intakes for total carbohydrate, fiber, and the essential fatty acids linoleic and α-linolenic acids are also higher during lactation (Figure 14.21).[23] Since the fatty acid composition of the mother's diet determines the fatty acid composition of her breast milk, adequate intake of omega-3 and omega-6 fatty acids ensures a healthy balance of these essential fatty acids in her breast milk.[78]

Even though some of the energy for lactation comes from maternal fat stores, the impact of lactation on maternal weight loss is variable. Beginning one month after birth, most lactating women lose 1 to 2 lb (0.5 to 1 kg)/month for six months. Some women will lose more, and others may maintain or even gain weight regardless of whether or not they breast-feed. Rapid weight loss is not recommended during lactation because it can decrease milk production. However, regular exercise can make weight loss easier and does not impair milk production.

Water Needs During Lactation The amount of milk a woman produces depends on how much her baby demands. The more the infant suckles, the more milk is produced. To avoid dehydration and ensure adequate milk production, lactating women need to consume about 1 L of additional water per day. The AI of 3.8 L/day, of which about 3.1 L is from drinking water and other beverages, is based on typical intake during lactation.[19] Consuming an extra glass of milk, juice, or water at every meal and whenever the infant nurses can help ensure adequate fluid intake.

Micronutrient Needs During Lactation The recommended intakes for several vitamins and minerals are increased during lactation to meet the metabolic needs of synthesizing milk and to replace the nutrients secreted in the milk itself (Figure 14.22). Maternal intake of some nutrients, including thiamin, riboflavin, vitamin B_6, vitamin B_{12}, vitamin A, vitamin D, selenium, and iodine, can affect milk composition.[79,80] When maternal intake of these is low, the amounts in milk are decreased. For example, low levels of vitamin B_{12} in the diets of vegan mothers can result in low levels of vitamin B_{12} in their milk. For other nutrients, including folate, calcium, iron, copper, and zinc, levels in the milk are maintained at the expense of maternal stores.[79] For example, much of the calcium secreted in human milk comes from an increase in maternal bone resorption so the RDA is not increased above nonlactating levels. Despite this, for most women, lactation does not affect the long-term risks of low bone density, osteoporosis, or fracture.[27] Iron needs are decreased during lactation because little iron is lost in milk, and, in most women, losses are decreased because menstruation is absent. The RDA for lactation is 9 mg/day, half that of nonlactating women.

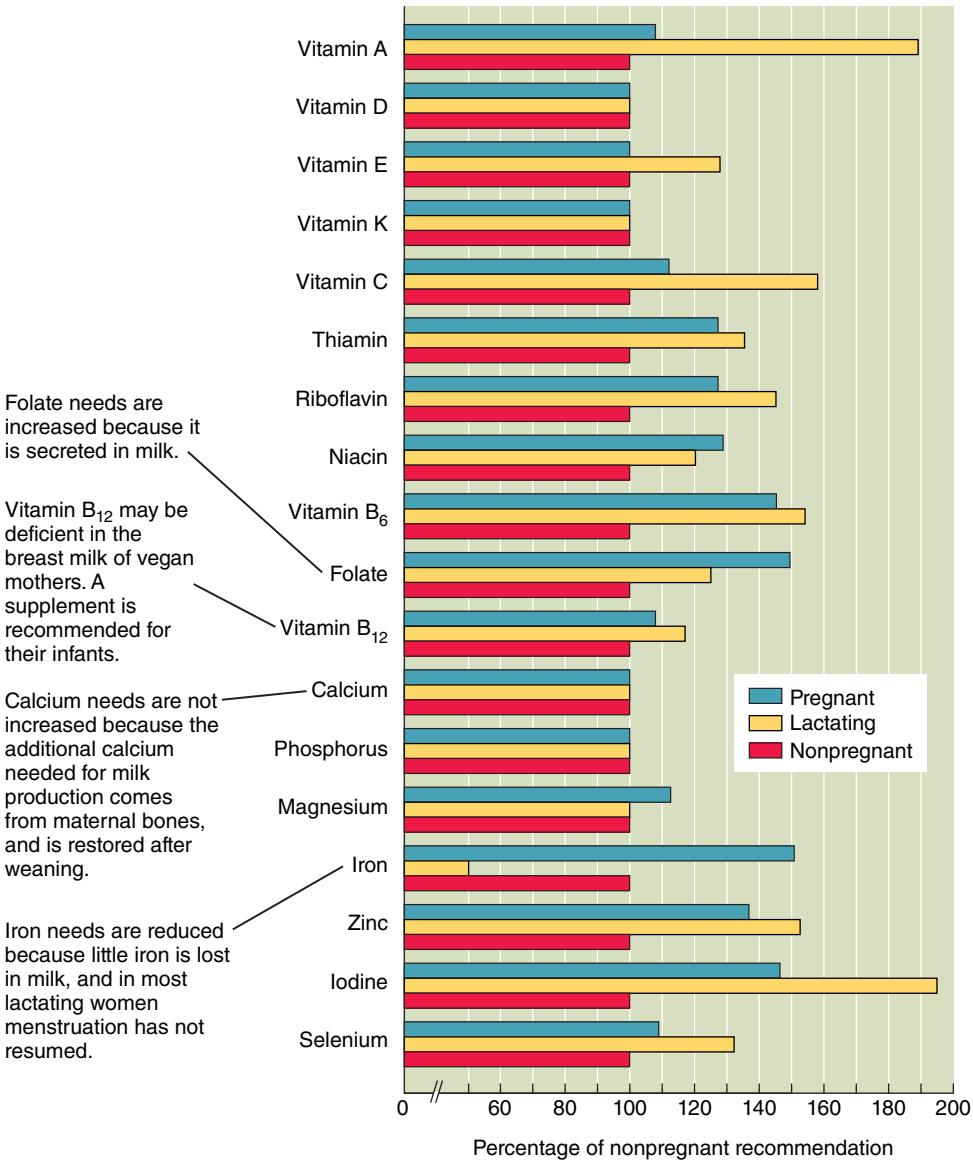


FIGURE 14.22 Micronutrient needs during lactation
This graph compares the vitamin and mineral recommendations for 25-year-old nonpregnant women and 25-year-old women during the third trimester of pregnancy and the first six months of lactation.

14.5 The Nutritional Needs of Infancy

LEARNING OBJECTIVES

- Compare the energy needs per kilogram of body weight of infants with those for adults.
- Compare the carbohydrate, protein, fat, and water recommendations for infants with those for adults.
- List micronutrients that are at risk for deficiency in infants.
- Explain the best way to monitor the adequacy of an infant's dietary intake.

When a child is born and the umbilical cord is cut, he or she suddenly becomes actively involved in obtaining nutrients rather than being passively fed through the placenta. The energy and

TABLE 14.5 Energy and Nutrient Needs of Infants Compared to Adults

Nutrient/energy	Infant recommendation (0–6 mo)	Adult recommendation
Energy[a]	493–606 kcal/day	2403–3067 kcal/day
	(~100 kcal/kg/day)	(~30 kcal/kg/day)
Protein	9.1 g/day	46–56 g/day
	1.52 g/kg/d	0.8 g/kg/day
Carbohydrate	At least 60 g/day	At least 130 g/day
	40% of energy intake[b]	45–65% of energy intake
Fat	50% of energy[b]	20–35% of energy
Linoleic acid	4.4 g/day[c]	12–17 g/day
α-Linolenic acid	0.5 g/day[d]	1.1–1.6 g/day
Fluid	0.7 L	2.7–3.7 L

[a]The energy values are based on EER prediction equations for infants 0–6 months of age and for adults ≥19 years of age.

[b]Based on the composition of human milk.

[c]Refers to all omega-6 polyunsaturated fatty acids.

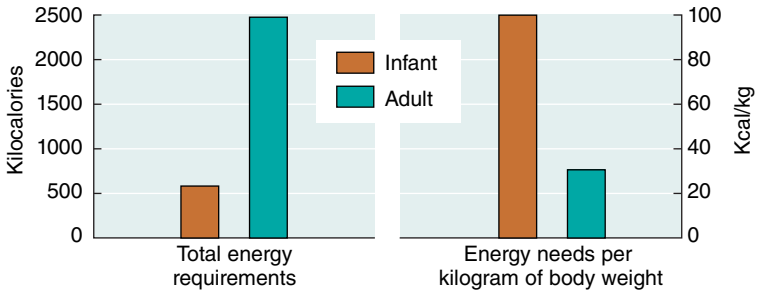
[d]Refers to all omega-3 polyunsaturated fatty acids.

nutrients the infant consumes must support his or her continuing growth and development and increasing level of activity (Table 14.5).

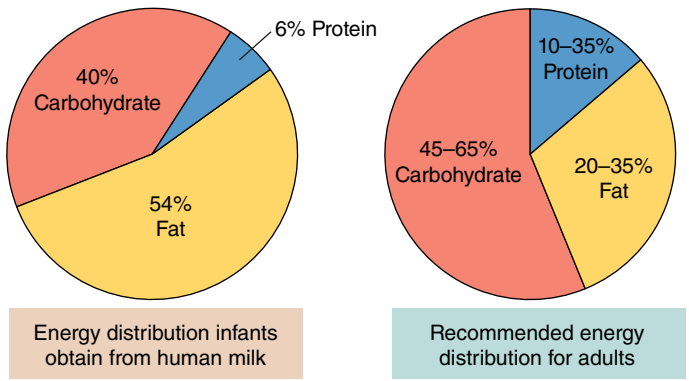
Energy Needs During Infancy

During the first few months after birth, growth is more rapid than at any other time of life. As a result, newborn infants need more calories per kilogram of body weight than at any other time (Figure 14.23A). EERs for infants are calculated from total energy expenditure plus the

FIGURE 14.23 Energy and macronutrient needs of infants and adults



A. The total amount of energy required by a newborn is less than the amount needed by an adult. When energy needs are expressed per kilogram of body weight, however, we see that infants require about three times more energy than an adult male.



B. A comparison of the distribution of calories from carbohydrate, fat, and protein in human milk with that recommended for an adult illustrates proportionally how much more fat infants need.

THINK CRITICALLY

Why is the recommendation for fat intake so much higher in infants than in adults?

energy deposited in tissues due to growth (see inside cover).[23] After the first few months, growth slows some and activity increases. Differences in growth rates and activity levels are reflected in the separate EER prediction equations for infants 0 to 3 months, 4 to 6 months, and 7 to 12 months.

Fat Recommendations

Healthy infants consume about 55% of their energy as fat during the first six months of life, and 40% during the second six months. This is far greater than the 20 to 35% of energy from fat recommended in the adult diet (Figure 14.23B). The high proportion of fat increases the energy density of the diet, allowing the infant's small stomach to hold enough to meet energy needs. An AI for total fat has been set at 31 g/day for infants from birth to 6 months of age and at 30 g/day for infants 7 to 12 months of age.

In addition to getting enough fat, infants need the right kinds of fat. A sufficient supply of the long-chain polyunsaturated fatty acids DHA (an omega-3 fatty acid) and ARA (an omega-6 fatty acid) is important for nervous system development. These fatty acids are constituents of cell membranes and are incorporated into brain tissue and the retina of the eye. Breast milk contains both of these fatty acids. Infant formulas supplemented with DHA and ARA are available, but the addition of these fatty acids to infant formulas is not required in the United States. Infants can synthesize these fatty acids from linoleic and α-linolenic acid, but since breast-fed infants have higher plasma concentrations of these long-chain polyunsaturated fatty acids than infants fed nonfortified formula, it is hypothesized that the rate of conversion may not be optimal. Evidence that inclusion of these fatty acids in infant formulas benefits growth, visual function, and cognitive development is equivocal (see **Debate: DHA-Fortified Infant Formulas**).[81] AIs for infants have been set for total omega-3 and total omega-6 fatty acids based on the amounts of these types of fatty acids in human milk.[23]

Carbohydrate Intake

Carbohydrate, like fat, is a major contributor to energy intake in the infant. The source of carbohydrate for breast-fed infants and most bottle-fed infants is lactose. About 40% of the energy in breast milk is from lactose. As the infant grows and solid foods are introduced into the diet, the percentage of calories from carbohydrate in the diet increases and the percentage from fat decreases.

Protein Requirements

The infant's protein requirement per unit of body weight is very high compared with the adult requirement: The AI is 1.52 g/kg/day from birth to 6 months of age, compared with the RDA of 0.8 g/kg/day for an adult (see Table 14.5). The ideal protein source for newborns is human milk. Infant formulas are designed to mimic its amino acid pattern. A diet too high in protein may lead to dehydration because the excretion of metabolic wastes produced when excess protein is consumed increases water loss.

Water Needs

Infants have a higher proportion of body water than adults and they lose proportionately more water in urine and through evaporation. Urine losses are high because the infant kidneys are not fully developed, and thus are unable to reabsorb much of the water that passes through them. Infants lose proportionately more water through evaporation because they have a larger surface area relative to their total body volume. These factors, in addition to the fact that infants cannot tell us they are thirsty, put them at risk for dehydration. Despite this, infants who are exclusively breast-fed do not require additional water. The AI is based on the volume of human milk consumed and the water content of the milk. It is set at 0.7 L/day for infants 0 to 6 months and at 0.8 L/day for older infants (7 to 12 months).[19] In older infants, some fluid is obtained from other beverages and foods. Although breast milk can meet fluid needs in

DEBATE

DHA-Fortified Infant Formulas

DHA and arachidonic acid (ARA) are polyunsaturated fatty acids that can be made in the body from the essential omega-3 fatty acid α-linolenic acid and the essential omega-6 fatty acid linoleic acid, respectively. Studies in animals indicate DHA and ARA are found in high concentrations in the brain and retina and are needed for normal vision and brain development.[82] Accumulation of these fatty acids in the brain and retina occurs most rapidly between the third trimester of pregnancy and 24 months of age, so adequate amounts are crucial during this developmental period. Some infant formulas in the United States are fortified with DHA and ARA, and advertisements suggest that they provide an advantage for infant development. Should all babies be fed fortified formula?

DHA and ARA are found in breast milk, so it seems logical that they should be added to infant formula. But, unlike most nutrients, the amounts in breast milk are variable, depending on maternal diet, so it is unclear what constitutes optimal levels. The amounts of these fatty acids transferred to the fetus by the placenta during the last trimester may be enough to ensure adequate brain deposition.[82] Infants born at term are also capable of synthesizing DHA and ARA, so those fed unfortified formula may be able to meet their needs if they have enough α-linolenic acid and linoleic acid in their diet. But there is wide individual variation in the ability to convert α-linolenic acid to DHA, and in some infants conversion may be too low for optimal brain and visual development.[83] Infants born before term cannot synthesize enough of these fatty acids, so these fatty acids must be included in formula for premature infants.[84]

So will higher intakes of DHA and ARA make children smarter and improve their vision? Numerous studies have explored the impact that postnatal intake of these fatty acids has on intelligence and vision. Some have found that higher intakes of DHA increase blood levels of DHA in infants and are associated with improvements in cognitive development or vision compared to infants with lower intakes.[82,85,86] But not all studies agree. Recent analyses that combine results from many studies have found that supplementing infant formula with DHA and ARA does not improve the IQ of infants or children.[81] The results of combined analyses on visual acuity are more mixed, with some analyses concluding that it improves vision in infants up to one year of age.[87]

Science Source/Photo Researchers, Inc.

The reported effects of fortified formulas have been inconsistent for a number of reasons. Differences may be due to variations in the DHA content of the formulas, the duration of formula feeding, and the methods used to assess visual acuity and cognitive development. Higher intelligence seen in breast-fed infants may be due more to factors such as maternal IQ, income level, and the amount of time mothers spend with their infants than to whether they are breast- or formula-fed.[88]

When it comes to brain and eye development, no one knows exactly how much DHA or ARA an infant needs. A direct link between fortified formula and better vision or higher IQ compared to the use of unfortified formula has yet to be established.[83] Fortified formulas may not make your baby smarter, but published literature has not found them to be harmful for infants.[89] Breast milk is always best, so the biggest downside to fortified formulas is that advertising may make new mothers believe that the formulas are as good as or better for their babies than breast milk.

THINK CRITICALLY: Why is breast milk still better than these fortified formulas?

healthy infants, additional fluids may be needed when water losses are increased by diarrhea or vomiting.

In the developing world, dehydration from diarrhea is the most common cause of infant death, and in the United States it kills one child each day. The cause of the diarrhea is usually a bacterial or viral infection. If an infant has diarrhea, fluid intake should be monitored carefully and a pediatrician should be contacted. Mixtures of sugar, water, and electrolytes are available to replace fluid losses.

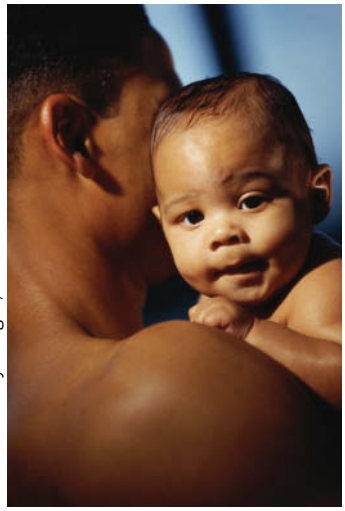
Micronutrient Needs of Infants

Human milk and formula are designed to meet the nutrient needs of young infants. Nonetheless, infants may still be at risk for deficiencies of iron, vitamin D, and vitamin K, and suboptimal levels of fluoride. The breast-fed infants of vegan mothers may also be at risk of vitamin B_{12} deficiency.

Iron Iron is the nutrient most commonly deficient in infants who are consuming adequate energy and protein. Iron deficiency is usually not a problem during the first 4 to 6 months of life because infants have iron stores at birth and the iron in human milk, though not particularly abundant, is very well absorbed. The AI for iron from birth to 6 months is only 0.27 mg/day.[44] After 4 to 6 months, iron stores are depleted but iron needs remain high to provide for hemoglobin synthesis, tissue growth, and iron storage. The RDA for infants 7 to 12 months jumps to 11 mg/day. To meet needs after 4 to 6 months, the diets of breast-fed infants should contain other sources of iron, such as iron-fortified rice cereal. Formula-fed infants can obtain iron from fortified formula.

Vitamin D Newborns are also potentially at risk for vitamin D deficiency. Breast milk is relatively low in vitamin D, so breast-fed infants who do not receive adequate exposure to sunlight, such as those living in cold climates, may not obtain enough vitamin D. It is recommended that all breast-fed and partially breast-fed infants be supplemented with 400 IU (10 μg)/day of vitamin D beginning in the first few days of life and continuing until they are consuming about 1 L (about 4 cups) of vitamin D-fortified formula or milk daily.[25,90] Infant formulas contain at least 400 IU (10 μg)/L of vitamin D. Most formula-fed infants consume nearly 1 L of formula per day after the first month of life, so they obtain enough vitamin D from the formula; those consuming less than 1 L/day should receive a vitamin D supplement of 400 IU (10 μg)/day. The amount of sun exposure necessary to maintain adequate levels of vitamin D in any given infant at any point in time is not easy to determine; light-skinned infants are more likely than darker-skinned babies to meet their vitamin D needs from sunlight (Figure 14.24).[90]

Vitamin K Vitamin K, which is essential for normal blood clotting, is another nutrient for which newborns are at risk of deficiency. Little of this vitamin crosses the placenta from mother to fetus, and because the gut is sterile at birth, no microbial vitamin K synthesis occurs. Breast milk is also low in vitamin K, so breast-fed infants are at risk of hemorrhage due to vitamin K deficiency. To prevent this, it is recommended that all infants receive a single intramuscular injection containing 0.5 to 1.0 mg of vitamin K after the first feeding is completed and within the first six hours of life.[91] This provides them with enough vitamin K to last until their intestines are colonized with the bacteria that synthesize it.



Photodisc/Getty Images, Inc.

FIGURE 14.24 Vitamin D and skin pigmentation
Dark skin pigmentation reduces the amount of vitamin D that can be synthesized in the skin, putting darker-skinned babies at greater risk for deficiency.

Fluoride Fluoride is important in the development of teeth even before they erupt. Breast milk is low in fluoride, and formula manufacturers use unfluoridated water in preparing liquid formula. Therefore, breast-fed infants, infants fed premixed formula, and those fed formula mixed with low-fluoride water are often supplemented beginning at 6 months of age. In areas where the drinking water is fluoridated, infants fed formula reconstituted with tap water should not be given fluoride supplements.

Vitamin B_{12} Breast milk and infant formula typically contain enough vitamin B_{12} to meet the infant's needs. An exception is the breast milk of vegan mothers, which may be deficient in vitamin B_{12}. Therefore, breast fed-infants of vegan mothers should be given vitamin B_{12} supplements.

Infant Growth and Nutritional Status

Although nutrient needs for infants are fairly well defined, it is difficult to calculate infants' actual nutrient intake—particularly if they are breast-feeding. The best indicator of adequate nourishment is normal growth. Most healthy infants follow standard patterns of growth, so their growth can be monitored using growth charts (see online Appendix E).[92]

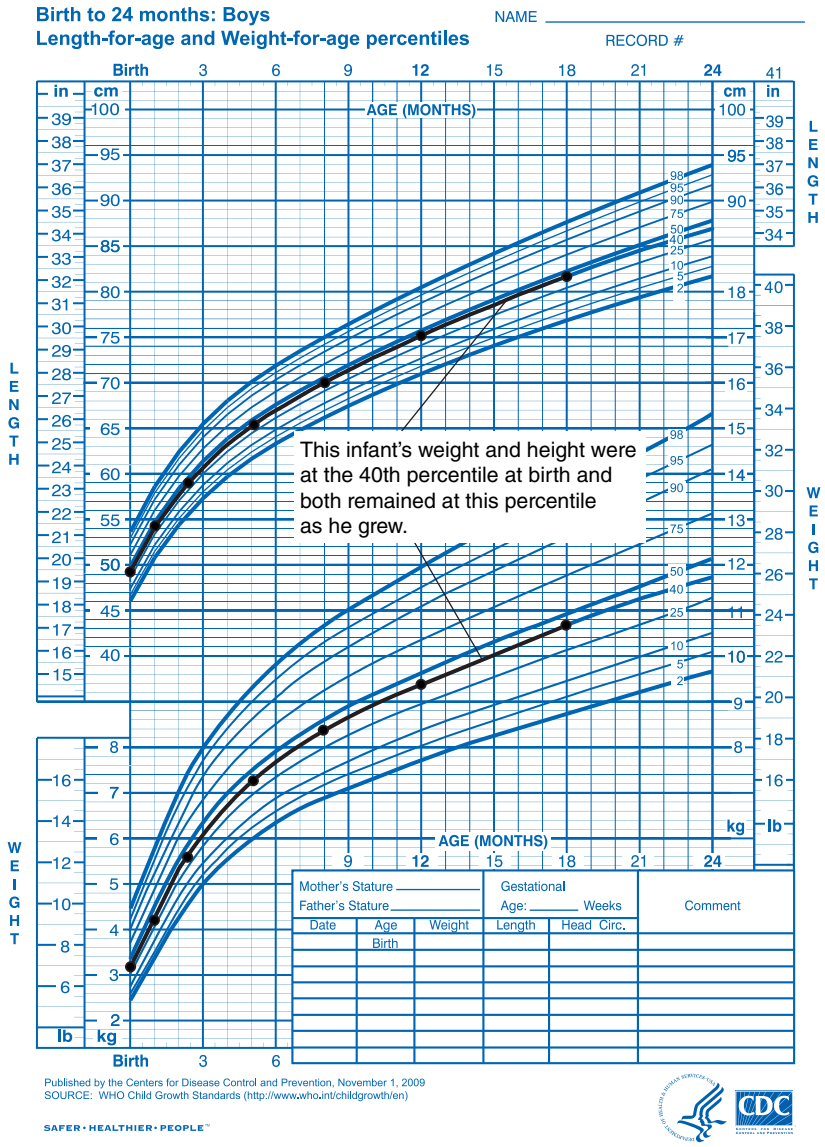


FIGURE 14.25 Monitoring infant growth
This growth chart for boys from birth to 24 months of age can be used to compare a boy's length and weight at a particular age to standards for optimal growth.[93] A similar chart is available for girls. Growth charts for this age group are also available to monitor weight for length and head circumference for age in boys and girls.

ANALYZE THE DATA

How much would a 15-month-old boy weigh if he were at the 50th percentile?

Infant Growth Charts The growth charts used to assess infant growth were developed by the World Health Organization and are based on growth patterns of breast-fed infants living in optimal conditions. To use a growth chart, the infant's weight and/or height is plotted on the graph, and the resulting percentile indicates where the infant's growth falls in relation to optimal growth patterns for infants of the same age (Figure 14.25).[93] For example, if a newborn boy is at the 20th percentile for weight, it means that 19% of healthy newborn boys weigh less and 80% weigh more. Babies usually continue at the same percentiles as they grow.

Whether an infant is 6 or 8 lb at birth, the pattern of growth should be approximately the same—rapid initially and slowing slightly as the infant approaches 1 year of age. A rule of thumb is that an infant's birth weight should double by 4 months and triple by 1 year of age. In the first year of life, most infants increase their length by 50%. Small infants and premature infants often follow a pattern parallel to but below the growth curve for a period of time, and then experience catch-up growth that brings them onto the growth curve in a place compatible with their genetic growth potential.

Abnormal Growth and Nutritional Status Slight fluctuations in growth rate are normal, but a consistent pattern of not following the growth curve or a sudden change in growth pattern is cause for concern and could indicate overnutrition or undernutrition. For example, a rapid increase in weight without an increase in height may indicate that the infant is being overfed. Just as there are critical periods in prenatal life, there are critical periods during infancy when nutrition can have permanent effects on growth and development and long-term health. Evidence suggests that accelerated weight gain in the first two years of life increases the risk of obesity, diabetes, high blood pressure, harmful blood lipid levels, and cardiovascular disease in adulthood.[94] A pattern of accelerated weight gain should be addressed early in life to reduce the likelihood of these chronic conditions later.

failure to thrive The inability of a child's growth to keep up with normal growth curves.

Growth that is slower than the predicted pattern indicates **failure to thrive**. This is a catch-all term for any type of growth failure in a young child. The cause may be a congenital condition, the presence of disease, poor nutrition, neglect, abuse, or psychosocial problems. The treatment is usually an individualized plan that includes adequate nutrition and careful monitoring by physicians, dietitians, and other health-care professionals. Undernutrition during infancy can permanently affect growth and development as well as health later in life. Because the first year of life is a critical period for brain development, undernutrition interferes with learning and affects behavior. Undernutrition in childhood is a risk factor for diabetes, high blood pressure, and cardiovascular disease in adulthood, especially in undernourished children who experience rapid weight gain after infancy.[95]

14.6 Feeding the Newborn

LEARNING OBJECTIVES

- Explain why breast-feeding is the first choice for nourishing a newborn.
- Discuss two situations in which bottle-feeding is recommended over breast-feeding.

Newborns are unique in that they have small stomachs, can consume only liquids, and have high nutrient requirements. The ideal food for the newborn is breast milk.[96] From birth until 4 to 6 months of age, infants don't need anything other than breast milk to meet nutrient needs. Solid food should not be introduced into the diet until the child is at least 4 to 6 months of age because the infant's feeding abilities and gastrointestinal tract are not mature enough to handle solid foods.

colic Episodes of inconsolable crying in an otherwise healthy infant between the ages of 2 weeks and 4 months. The cause is unknown.

A relatively common problem in infants is **colic**. Colic involves daily periods of inconsolable crying that cannot be stopped by holding, feeding, or changing the infant. Colic usually begins at a few weeks of age and continues through the first two to three months. It occurs in both breast- and bottle-fed infants. Although its cause is unknown, it is hypothesized that colic is related to intestinal gas caused by milk intolerance, food allergies or intolerance, changes in the intestinal microbiota, improper feeding practices, or immaturity of the gastrointestinal tract or central nervous system.

Meeting Nutrient Needs with Breast-Feeding

It is estimated that if 90% of women in the United States breast-fed their babies, annual health-care costs would be decreased by $13 billion.[96] Breast milk meets the nutrient needs of the human newborn and requires no special preparation, and the amount available varies with demand. Thus, breast-feeding is the preferred form of nutrition for nearly all infants.[96,97]

Nutritional Advantages of Breast Milk The nutrient composition of breast milk is specifically designed for the human infant and changes over time as the infant develops, meeting the nutrient needs of the child for up to the first year of life. The first fluid that is produced by the breast after delivery is colostrum. This yellowish fluid is higher in water, protein, immune factors,

minerals, and some vitamins than mature breast milk. It is produced for up to a week after delivery. While colostrum is produced, it may seem that the newborn is not receiving enough to eat; however, supplemental bottle-feedings are not necessary. The nutrients in colostrum meet infant needs until mature milk production begins. Colostrum also has beneficial effects on the gastrointestinal tract, acting as a laxative that helps the baby excrete the thick, mucousy stool produced during life in the womb.

Lactalbumin is the predominant protein in human milk. In the infant's stomach it forms a soft, easily digested curd. The amino acids methionine and phenylalanine, which are difficult for the infant to metabolize, are present in lower amounts in human milk proteins than in cow's milk proteins. Human milk is also a good source of taurine, an amino acid needed for bile salt formation and eye and brain function.

The lipids in human milk are easily digested. They are high in cholesterol and the fatty acids linoleic acid, ARA, and DHA, which are essential for normal brain development, eyesight, and growth. The fat content of breast milk changes throughout a feeding, gradually increasing during the nursing session. Thus, for the baby to attain satiety and obtain adequate energy, it is important for nursing to continue long enough for the infant to obtain the higher-fat milk.

Lactose is the primary carbohydrate in human milk. It is digested slowly so it stimulates the growth of acid-producing bacteria. It also promotes the absorption of calcium and other minerals and provides a source of the sugar galactose for nervous system development.

Breast milk is low in sodium, and the zinc, iron, and calcium present are in forms that are easily absorbed. About 50% of the iron in human milk is absorbed, compared with only 2 to 30% from many other foods.

Other Advantages of Breast-Feeding Breast-feeding can be a relaxing, emotionally enjoyable interaction for both mother and infant. In addition to its nutritional advantages, breast-feeding is convenient, inexpensive, and has psychological and physiological benefits for both mother and child (Figure 14.26).

FIGURE 14.26 The benefits of breast-feeding[96]

Benefits for infants
- Provides optimum nutrition
- Enables strong bonding with mother
- Enhances immune protection
- Reduces allergies
- Decreases ear infections, respiratory illnesses, and asthma
- Reduces the likelihood of constipation, diarrhea, or chronic digestive diseases
- Reduces risk for SIDS
- Lowers risk for obesity, type 1 and 2 diabetes, heart disease, hypertension, high blood cholesterol, and childhood leukemia
- Aids in the development of the facial muscles, speech development, and correct formation of the teeth
- Lessens the risk of overfeeding

Cusp and Flirt/Masterfile

Benefits for mothers
- Provides relaxing, emotionally enjoyable interaction; strengthens bonding with infant
- Reduces financial costs
- Requires less preparation and clean-up time; always available
- Causes uterine contractions that help the uterus return to its normal size more quickly after delivery
- Increases energy expenditure, which may speed return to prepregnancy weight
- Lowers risk of developing type 2 diabetes and breast and ovarian cancers
- Improves bone density and decreases risk of fractures
- Inhibits ovulation, lengthening the time between pregnancies; however, breast-feeding cannot be relied on for birth control
- Decreases the risk of postpartum depression
- Enhances self-esteem in the maternal role

During the first few months of life, the immune factors provided, first by colostrum, and later by mature milk, compensate for the infant's immature immune system. These factors include antibody proteins and immune system cells that pass from the mother into her milk. Breast milk also contains a number of enzymes and other proteins that prevent the growth of harmful microorganisms. Several carbohydrates have been identified that protect against disease-causing microorganisms, including viruses that cause diarrhea. One carbohydrate favors the development of a healthy microbiota in the infant's colon, which inhibits the growth of harmful bacteria. Breast-fed babies have fewer allergies, ear infections, respiratory illnesses, and urinary tract infections than formula-fed babies, and have fewer problems with constipation and diarrhea. There is also evidence that breast-feeding protects against sudden infant death syndrome, diabetes, and chronic digestive diseases.[97]

In addition to providing disease protection, the strong suckling required by breast-feeding aids in the development of facial muscles, which help in speech development and the correct formation of teeth. Breast-fed babies are also less likely to be overfed, because the amount of milk consumed cannot be monitored visually. In bottle-feeding, it is often tempting to encourage the baby to finish the entire bottle whether or not he or she is hungry.

For the mother, breast-feeding has the advantage of providing a readily available and inexpensive source of nourishment for her infant (see Figure 14.26). It requires no preparation or bottles and nipples that must be washed. It is more ecologically beneficial because it doesn't require energy for manufacture or generate waste from discarded packaging. Physiologically, breast-feeding causes contractions that help the mother's uterus return to normal size more quickly and may promote weight loss in some women. Women who breast-feed may have a lower risk of developing osteoporosis and breast and ovarian cancer. Lactation also inhibits ovulation, lengthening the time between pregnancies; however, it does not reliably prevent ovulation and so cannot be effectively used for birth control. Oral contraceptives can be used immediately postpartum, but those containing only progestin are preferable because they do not affect milk volume or composition. Oral contraceptives containing estrogen may decrease milk volume.

How Much Is Enough? A strong, healthy baby will be able to suckle shortly after birth. Within a week, milk production and breast-feeding are usually fully established. During the early weeks of breast-feeding, the infant should be fed about 8 to 12 times every 24 hours (every 2 to 3 hours) or whenever the infant shows early signs of hunger. A feeding should last approximately 8 to 12 minutes at each breast. A well-fed newborn should urinate enough to soak six to eight diapers a day and gain about one-third to one-half pound per week.

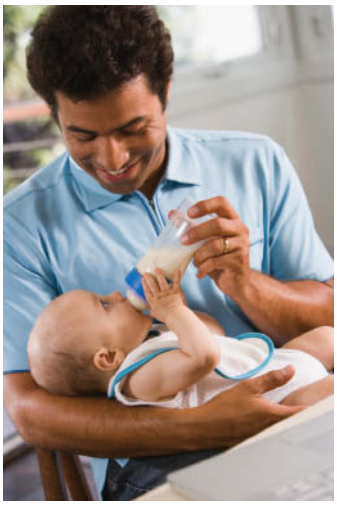
How Long Should Breast-Feeding Continue? Physiologically, lactation can continue as long as suckling is maintained. Breast-feeding alone is sufficient to support optimal growth for about 6 months, and the American Academy of Pediatrics and many other health organizations recommend exclusive breast-feeding for the first 6 months of life.[97] Breast-feeding along with supplemental feeding of solids is recommended for at least the first year of life and beyond for as long as mutually desired by mother and child. After 12 months, the baby no longer needs breast milk to meet nutrient needs. As the infant obtains more and more of its energy from solid foods, milk production decreases due to reduced demand by the infant. However, breast-feeding beyond 12 months continues to provide nutrition, comfort, and an emotional bond between mother and child. In developing nations it may continue to give children the nutritional advantage needed to fight infection and stay healthy. The World Health Organization recommends that infants in developing nations be breast-fed for two years or more.[98]

Practical Aspects of Breast-Feeding Breast-feeding does not always come naturally to mother or infant and can require practice and patience. Effective suckling by the infant and relaxation of the mother are essential to successful breast-feeding. Some foods and other substances in the mother's diet, such as garlic or spicy foods, contain chemicals or flavors that pass into breast milk and cause adverse reactions in some babies. These reactions seem to be individual to the mother and child. As long as a food does not affect the infant's response to feeding, it can be included in the mother's diet.

Caffeine in the mother's diet can make the infant jittery and excitable, so large amounts should be avoided while breast-feeding. Alcohol, which is harmful for infants, passes into breast

milk. It is most concentrated an hour to an hour and a half after consumption and is cleared from the milk at about the same rate at which it disappears from the bloodstream. Therefore, occasional limited alcohol consumption while breast-feeding is probably not harmful if intake is timed to minimize the amount present in milk when the infant is fed.

Breast-feeding does not mean that a mother must be available for every feeding. Milk may be pumped from the breast and stored for later feedings (Figure 14.27). Since pumped milk is exposed to pumps and bottles, care must be taken to avoid contamination. If pumped milk is not immediately fed to the baby, it should be refrigerated. It can be kept refrigerated for 24 to 48 hours, but if it will not be used within that period, it should be frozen in clean containers. Warming breast milk in a microwave is not recommended because this destroys some of its immune properties and it may result in dangerously hot portions of the milk. The best way to warm milk is by running warm water over the bottle.



Jupiter Images/FoodPix/Getty Images, Inc.

FIGURE 14.27 Pumped breast milk
Breast milk can be frozen and stored so other caregivers can feed the baby from a bottle when the mother is not available.

Meeting Nutrient Needs with Bottle-Feeding

A hundred years ago, a baby who could not be breast-fed had little chance of survival. Today, with the availability of infant formulas, babies who cannot breast-feed can still thrive. Special formulas are available to meet the needs of premature infants and infants with allergies and genetic abnormalities.

Nutritional Composition of Infant Formula Infant formulas can never duplicate the living cells, active hormones, enzymes, and immune system molecules in human milk, but formulas today try to replicate human milk as closely as possible in order to match the growth, nutrient absorption, and other parameters obtained with breast-feeding (Table 14.6). Commercially prepared infant formulas are required by the FDA to provide minimum amounts of 29 nutrients based on levels in breast milk. Because the American Academy of Pediatrics recommends iron-fortified formulas, most infant products are fortified with iron. Some formulas are supplemented with the long-chain polyunsaturated fatty acids DHA and ARA. These are found in breast milk and are thought to help infant development. Formulas supplemented

TABLE 14.6 Nutritional Composition of Breast Milk and Infant Formula

Nutrient	Amount in breast milk	Amount in formula	Comparisons
Protein	1.8 g/100 mL	1.4 g/100 mL	The relatively low protein content of human milk and formula protects the immature infant kidneys from a too-high load of nitrogen wastes. Alpha-lactalbumin, the predominant protein in human milk, forms a soft, easily digested curd in the infant's stomach. Most formula is made from cow's milk that is modified to mimic the protein concentration and amino acid composition of human milk.
Fat	4 g/100 mL	4.8 g/100 mL	The fat in human milk is easily digested. Human milk is high in cholesterol and the essential fatty acids linoleic acid and α-linolenic acid, as well as their long-chain derivatives ARA and DHA, which are essential for normal brain development, eyesight, and growth. The fat in formula is derived from vegetable oils and provides linoleic and α-linolenic acid. Some formulas are also supplemented with ARA and DHA.
Carbohydrate	7 g/100 mL	7.3 g/100 mL	Lactose, the primary carbohydrate in human milk and most formulas, enhances calcium absorption. Because it is digested slowly, it stimulates the growth of beneficial acid-producing bacteria. Oligosaccharides in milk protect against respiratory and gastrointestinal disease.
Sodium	1.3 mg/100 mL	0.7 mg/100 mL	Because breast milk and formula are both low in sodium, the fluid needs of breast-fed and formula-fed infants can be met without an excessive load on the kidneys.
Calcium **Phosphorus**	22 mg/100 mL 14 mg/100 mL	53 mg/100 mL 38 mg/100 mL	The ratio of calcium to phosphorus in breast milk and formula enhances calcium absorption.
Iron **Zinc**	0.03 mg/100 mL 3.2 mg/100 mL	0.1 mg/100 mL 5.1 mg/100 mL	Iron and zinc are present in limited amounts in breast milk but are readily absorbed. Most infant formulas are fortified with iron and zinc because the forms present are less absorbable than those in breast milk.
Vitamin D	4 IU/100 mL	41 IU/100 mL	Formulas are fortified with vitamin D, which is present at low levels in breast milk.

with fatty acids are more expensive, and it is still not clear whether they improve growth or visual or neurological development (see *Debate: DHA-Fortified Infant Formulas*).

Most infant formula is based on cow's milk, but unmodified cow's milk should never be fed to infants. Cow's milk is difficult for infants to digest and has a higher protein and mineral content than breast milk or formula, so it taxes the infant kidneys and predisposes the infant to dehydration. Young infants may also become anemic if fed cow's milk because it contains little absorbable iron and can lead to iron loss by causing small amounts of gastrointestinal bleeding. Unmodified goat's milk is also not recommended for infants. Although it is less allergenic and more easily digested than cow's milk, it is low in vitamin D as well as iron, vitamin B_{12}, and folate, which can lead to an iron deficiency or macrocytic anemia. Cow's milk and goat's milk can be introduced at about 12 months of age, when organ systems are more mature and missing nutrients can be provided by other foods.

When Is Bottle-Feeding Recommended? In certain situations, breast-feeding is not the best choice. For example, an infant who is small or weak may not have the strength to receive adequate nutrition from breast-feeding. In this case, pumped breast milk or formula can be offered to the infant in a bottle. Infants with allergies, premature infants, and those with genetic abnormalities that alter dietary needs may require bottle-feeding with special formulas.

Some infants cannot tolerate human milk. In these cases, bottle-feeding with a cow's milk- or soy-based formula may be acceptable. For infants who are allergic to cow's milk and soy protein, elemental formulas made from predigested proteins, called *protein hydrolysates*, are an option.

Bottle-feeding may be the only option for babies with genetic abnormalities that prevent the normal metabolism of specific nutrients. For instance, infants with the genetic disease phenylketonuria (PKU) lack an enzyme needed to metabolize the amino acid phenylalanine (see Chapter 6). If a child with PKU is fed breast milk, which contains proteins with the amino acid phenylalanine, the by-products of phenylalanine metabolism accumulate and cause brain damage. Bottle-feeding infants with PKU a special formula that provides only enough phenylalanine to meet the need for protein synthesis can prevent brain damage. Because this special diet must be started as soon as possible, infants born in the United States and Canada are tested for PKU at birth.

© Sally and Richard Greenhill/Alamy Limited

FIGURE 14.28 Preparing infant formula
Formulas are marketed in three basic forms: ready-to-feed, liquid concentrates, and powdered. Ready-to-feed formulas require no preparation and are packaged in many sizes. Liquid concentrates and powdered formulas are prepared for use by mixing them with specific amounts of water. When properly prepared, all provide the needed nutrients in appropriate concentrations.

Bottle-feeding may also be recommended to prevent the transmission of drugs and disease via breast milk. Women who are taking medications should check with their physician on whether it is safe to breast-feed. If prescription drugs are taken by the mother for only a short time, a breast pump may be used to maintain milk production and the milk discarded until the medication is no longer needed. Because alcohol and drugs such as cocaine and marijuana can be passed to the baby in breast milk, alcohol and drug-addicted mothers are counseled not to breast-feed. Nicotine from cigarette smoke is also rapidly transferred from maternal blood to milk, and heavy smoking may decrease the supply of milk. Tuberculosis and certain viral infections can be transmitted to the infant in breast milk, but common illnesses such as colds, flu, and skin infections should not interfere with breast-feeding. Human immunodeficiency virus (HIV), the virus that causes AIDS, can be transmitted to the infant in breast milk. In the United States, women who are infected with HIV are advised not to breast-feed, but in developing nations, the risk of malnutrition associated with not breast-feeding often outweighs the risk of passing this infection on to the infant.[98]

How Much Is Enough? As with breast-fed infants, bottle-fed infants should be fed on demand every few hours. Newborns have small stomachs, so at each feeding they may consume only a few ounces of formula. As the infant grows, the amount consumed at each feeding will increase to 4 to 8 oz. Caregivers should respond to cues from the infant that hunger is satisfied, even if a bottle of pumped breast milk or formula is not finished. Encouraging infants to finish every bottle can result in overfeeding and excess weight gain. As with breast-fed infants, adequate intake can be judged from the amount of urine produced and the rate of growth.

Practical Aspects of Bottle-Feeding Infant formula must be prepared carefully in order to avoid mixing errors and contamination. If the proper measurements are not used in preparing formula, the child can receive an excess or deficiency of nutrients and an improper ratio of nutrients to fluids (Figure 14.28).

14.28). If the water and all the equipment used in preparing formula are not clean or if the prepared formula is left unrefrigerated, food-borne illness may result. Because sanitation is often a problem in developing nations, infections that lead to diarrhea and dehydration occur more commonly in formula-fed than in breast-fed infants.

Commercially prepared ready-to-feed formulas, liquid concentrates, and powders contain no harmful microorganisms. To avoid introducing harmful microorganisms, the water used to dilute concentrates or mix powdered formula should be boiled for one to two minutes and allowed to cool before mixing. Hands should be washed before preparing formula, and bottles and nipples should be washed in a dishwasher or placed in a pan of boiling water for five minutes. Formula should be prepared immediately before a feeding, and any excess should be discarded. Opened cans of ready-to-feed and liquid concentrate formula should be covered and refrigerated and used within the time indicated on the can. Formula may be fed either warm or cold, but the temperature should be consistent.

Biophoto Associates/ Science Source Images

FIGURE 14.29 Nursing bottle syndrome
Putting infants to bed with a bottle causes rapid and serious decay of the upper teeth, referred to as nursing bottle syndrome.

The position of the child is important during feeding. The infant's head should be higher than his or her stomach, and the bottle should be tilted so that there is no air in the nipple. If the hole in the nipple is too large, the infant may feel full before receiving adequate nutrition. If the hole is too small, the infant may tire before nutrient needs are met. Just as breast-fed infants alternate breasts, bottle-fed infants should be held alternately between the left and right arms to promote equal development of the head and neck muscles.

Infants should never be put to bed with a bottle of formula or other sweetened liquids. At night, while the child sleeps, the flow of saliva is decreased and the sugary formula is allowed to remain in contact with the teeth for many hours. This causes the rapid and serious decay of the upper teeth referred to as **nursing bottle syndrome**. Usually, the lower teeth are protected by the tongue and are unaffected (Figure 14.29).

nursing bottle syndrome
Extreme tooth decay in the upper teeth resulting from putting a child to bed with a bottle containing milk or other sweet liquids.

OUTCOME

UpperCut Images/Getty Images, Inc.

© Miroslav Ferkuniak/iStockphoto

After her doctor's visit, Jasmine realized that the health of her baby was more important to her than whether or not she needed to lose a few pounds after the delivery. Her doctor helped her understand that she needed to eat a diet higher in energy, protein, and many micronutrients than the one she consumed before she became pregnant. Jasmine took a prenatal supplement to help meet her micronutrient needs, but a pill can't provide the calories and protein she needs to build new tissues or fiber to prevent constipation. To construct her diet, Jasmine looked up her MyPlate Daily Food Plan. It called for an increase in her intake of grains and vegetables, which added energy, fiber, protein, folate, and vitamin C to her diet, and an increase in foods from the protein food group, which provided iron, protein, zinc, and B vitamins. She continued to exercise regularly, but switched to walking and swimming, which were safer and more comfortable when her belly was large. She skipped sugary sodas and was able to keep her blood sugar normal throughout her pregnancy. After nine months, Jasmine had gained 32 lb and gave birth to a healthy 7 lb 8 oz baby boy. She breast-fed him for a year. While she was lactating, her need for energy, fluid, and certain micronutrients continued to be higher than they were before her pregnancy. **Although she felt as if she was eating all the time, after six months she was back to her prepregnancy weight.**

SUMMARY

14.1 The Physiology of Pregnancy

- Pregnancy begins with the fertilization of an egg by a sperm. About two weeks after fertilization, implantation is complete. The embryo grows, and the cells differentiate to form the organs and structures of the body. Growth and maturation continue in the fetal period, which begins at 9 weeks, and continues until birth, about 38 weeks after fertilization.
- During pregnancy, the placenta develops; maternal blood volume increases; the uterus and supporting muscles expand; body fat is deposited; the heart, lungs, and kidneys work harder; the breasts enlarge; and total body weight increases. Changes in the mother and growth of the fetus contribute to weight gain. Recommended weight gain during pregnancy is 25 to 35 lb (11 to 16 kg) for normal-weight women. Too little or too much weight gain can place both mother and baby at risk. Weight loss should never be attempted during pregnancy. Normal-weight, underweight, overweight, and obese mothers should all gain weight at a steady rate during pregnancy, but the total amount of weight gain recommended depends on prepregnancy weight.
- During healthy pregnancies, a carefully planned program of moderate-intensity exercise can be safe and beneficial.
- Changes in blood volume and hormone levels and the enlargement of the uterus can result in edema, morning sickness, heartburn, constipation, and hemorrhoids during pregnancy.
- The hypertensive disorders of pregnancy include chronic hypertension, gestational hypertension, and preeclampsia, which can lead to life-threatening eclampsia. Gestational diabetes can result in a large-for-gestational-age baby.

14.2 The Nutritional Needs of Pregnancy

- During pregnancy, the requirements for energy, protein, water, and some vitamins and minerals rise above levels for nonpregnant women. The need for B vitamins is increased to support increased energy and protein metabolism. The RDA for calcium is not increased because the greater need during pregnancy is met by an increase in absorption. Vitamin D deficiency is a concern, particularly for darker-skinned women. Adequate folic acid early in pregnancy reduces the risk of neural tube defects. Iron is needed for red blood cell synthesis, so requirements are high and deficiency is common during pregnancy.
- Even with a nutrient-dense diet that follows a MyPlate Daily Food Plan, supplements of folic acid and iron are recommended during pregnancy.

14.3 Factors That Increase the Risks of Pregnancy

- Nutritional status is important before, during, and after pregnancy. Poor nutrition before pregnancy can decrease fertility or lead to a poor pregnancy outcome. Malnutrition during pregnancy can affect fetal growth and development and the risk that the child will develop chronic disease later in life.
- Poor maternal health status, age younger than 20 or older than 35 years, a short interval between pregnancies, a history of poor reproductive outcomes, and poverty all increase the risk of complications for the mother and baby.
- Because the embryo and fetus are developing and growing rapidly, they are susceptible to damage from physical, chemical, or other environmental teratogens. Mercury in food, food-borne pathogens, cigarette smoking, alcohol use, and certain prescription and illegal drugs can interfere with growth and development of the embryo and fetus.

14.4 Lactation

- Milk production and letdown are triggered by the hormones prolactin and oxytocin, respectively. They are secreted in response to the suckling of the infant.
- Lactation requires energy and nutrients from the mother to produce adequate milk. The energy for milk production comes from the diet and maternal fat stores. During lactation, the need for water and many vitamins and minerals is even greater than during pregnancy.

14.5 The Nutritional Needs of Infancy

- Newborns grow more rapidly and require more energy and protein per kilogram of body weight than at any other time in life. Fat and water needs are also proportionately higher than those of adults.
- A diet that meets energy, protein, and fat needs may not necessarily meet the needs for iron, fluoride, and vitamins D and K.
- Growth, which is assessed using growth charts, is the best indicator of adequate nutrition in an infant. Growth charts can be used to compare an infant's growth with the growth of healthy infants of the same age.

14.6 Feeding the Newborn

- Breast milk is the ideal food for new babies. It is designed specifically for the human newborn; is always available; requires no special equipment, mixing, or sterilization; and provides immune protection.
- Infant formulas are patterned after human milk and provide adequate nutrition to the baby. Infant formulas are the best option when the mother is ill or is taking prescription or illicit drugs, or when the infant has special nutritional needs. The major disadvantages of formula feeding are the potential for bacterial contamination, overfeeding, and the possibility of errors in mixing formula.

CHAPTER OUTLINE

15.1 Starting Right for a Healthy Life

What Are American Children Eating?

How Poor Food Choices Are Impacting Children's Health

Healthy Eating Is Learned for Life

15.2 Nourishing Infants, Toddlers, and Children

Monitoring Growth

Nutrient Needs of Infants and Children

Meeting Infants' and Children's Nutrient Needs

15.3 Nutrition and Health Concerns in Infants and Children

Food Allergies and Intolerances

Dental Caries

Diet and Attention Deficit/Hyperactivity Disorder

Lead Toxicity

Childhood Obesity

15.4 Adolescents

The Changing Body: Sexual Maturation

Nutrient Needs of Adolescents

Meeting Adolescents' Nutrient Needs

15.5 Special Concerns of Teenagers

How Vegetarian Diets Affect Nutritional Health

Eating for Appearance and Performance

Oral Contraceptive Use

Teenage Pregnancy

Tobacco Use

Alcohol Use

(©iStockphoto)

LWA/The Image Bank/Getty Images, Inc.

Nutrition from Infancy to Adolescence

15

CASE STUDY

Blend Images/SUPERSTOCK

Thirteen-year-old Felicia has been overweight since she was 3. When she started eighth grade, she was 5′ tall and weighed 140 lb. At a recent checkup, her physician noted that her blood pressure was elevated and her cholesterol levels were at the high end of normal. The physician recommended that Felicia and her mother meet with a dietitian to discuss ways to manage Felicia's weight and improve her diet.

At that meeting, Felicia explained that she knows she should eat less and exercise more but can't find a way to make those changes. She spends most of her school day sitting at a desk. Physical education class meets only twice a week. She has to eat what is on the school menu because she gets a reduced-cost lunch as part of the National School Lunch Program. It is difficult for her to exercise after school because she goes to the library study program until her mother gets out of work at 5 PM. Felicia gets a little more exercise on weekends by seeing friends, but they often go out for ice cream or fast food, and Felicia feels left out if she doesn't join them.

The dietitian helps Felicia figure out some changes that will help reduce her calorie intake. She also works with Felicia's mother to plan low-calorie, nutritious dinners that the entire family will enjoy. Finally, Felicia and her mother decide to get some regular exercise by walking after dinner. These evening walks soon progress to activities that include the whole family, such as skating and bike riding. **Felicia is on the right track, because good nutrition and exercise patterns learned early in life are key to maintaining long-term health.**

15.1 Starting Right for a Healthy Life

LEARNING OBJECTIVES

- Discuss the healthfulness of children's diets in the United States.
- Give examples of how environment influences children's nutrient intake.
- Explain the impact of diet and lifestyle during childhood on the risk of chronic disease.

Nutrient intake during childhood helps shape the adult that a child will become. A nutritious well-balanced eating pattern and active lifestyle allow children to grow to their potential, and can prevent or delay the onset of the chronic diseases that plague American adults. Therefore, teaching healthy eating and exercise habits will benefit not only today's children, but tomorrow's adults (Figure 15.1).

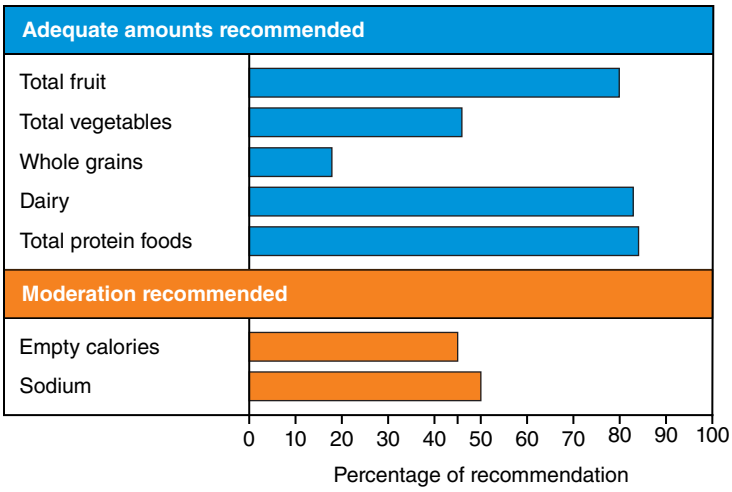
What Are American Children Eating?

The diets of children today are not as healthy as they could be. Children and adolescents in the United States do not eat enough foods rich in calcium, potassium, vitamin D, and dietary fiber, such as whole grains, fruits, vegetables, dairy products, and seafood (Figure 15.2).[1,2] They consume more sodium and empty calories than recommended: Empty calories from added sugars and solid fats make up 40% of the calories consumed each day by children and adolescents ages 2 to 18 years. Approximately half of these empty calories come from six sources: soda, fruit drinks, dairy desserts, grain desserts, pizza, and whole milk.[3]

Children today eat larger portions and more calories from snacks and meals prepared away from home than children did 40 years ago. Larger portions increase calorie intake because people eat more when more food is put in front of them. For example, when given lunch portions double the age-appropriate standard, children ages 3 to 5 consumed 15% more calories than when served the standard portion.[4] Calories from snacks have increased both because children eat more snacks and the snacks are more calorically dense; between 1977–1978 and 2005–2010 the number of eating occasions (meals plus snacks) increased from 3.9 to 5.1, and energy intake from snacks increased by 108 kcal/day.[5] Meals prepared away from home have been shown to be higher in

© Hongqi Zhang/iStockphoto

FIGURE 15.1 Developing healthy eating habits
The foods and nutrients this child eats influence the eating habits and health of the adult he will become.



ANALYZE THE DATA

Of the food, nutrient, and calorie recommendations shown on the graph, which is consumed in an amount farthest from what is recommended?

FIGURE 15.2 How good are children's diets?
The Healthy Eating Index scores diets based on how well they meet the recommendations of the Dietary Guidelines and MyPlate. A score of 100% indicates that on average the recommendation was met or exceeded. For some foods and nutrients, the goal is to consume adequate amounts, while for others the focus is on moderation. For all, a higher score indicates that intake is closer to recommendations. Children ages 2 to 17 came closest to meeting recommendations for consumption of fruit, protein foods, and dairy products. They did not eat enough vegetables or whole grains, and consumed too many empty calories and too much sodium.[1]

calories and to contribute fewer servings of fruits, vegetables, whole grains, and dairy than food prepared at home.[2,6]

How Poor Food Choices Are Impacting Children's Health

Children's current patterns of diet and activity are associated with an increased risk of obesity. Like adult obesity, childhood obesity increases the risk of developing type 2 diabetes, elevated blood cholesterol, hypertension, and other chronic conditions.

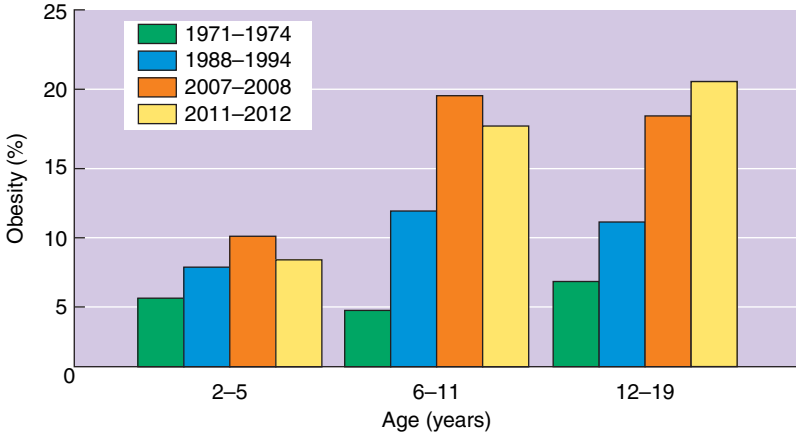


FIGURE 15.3 Incidence of obesity among U.S. children and adolescents
Results from the National Health and Nutrition Examination Surveys illustrate the changes in the incidence of obesity among children and adolescents from 1971–1974 to 2011–2012.[8]

Obesity Overweight and obesity are major problems in children in the United States. More than twice as many children and almost three times as many teens are overweight or obese today as in 1980. About 17% of children and teens ages 2 to 19 are now obese (Figure 15.3).[7,8]

In addition to the health issues, children and adolescents in the United States who are obese face social and psychological challenges. They are less well accepted by their peers than normal-weight children and are frequently ridiculed and teased. They often have poor self-image and low self-esteem, particularly during the teenage years.[9] Adolescents who are obese may be discriminated against by adults as well as by their peers. This contributes to feelings of rejection, social isolation, and low self-esteem. The isolation of obese adolescents from teen society results in boredom, depression, inactivity, and withdrawal—all of which can cause an increase in eating and a decrease in energy output, worsening the problem (Figure 15.4).

Robert E. Daemmrich/Getty Images, Inc.

FIGURE 15.4 Social isolation
The social isolation experienced by many overweight teens contributes to inactivity and overeating, further exacerbating their weight problems.

Type 2 Diabetes Until recently, type 2 diabetes was considered a disease that affected primarily adults over age 40, but it is now on the rise among America's youth. More than 5000 U.S. children and adolescents are diagnosed with type 2 diabetes each year. Most of these cases are in children 10 to 19 years of age, and the incidence is higher among minorities.[10] The typical picture of type 2 diabetes in this population is a child from age 10 to mid-puberty, overweight, with a family history of the disease. Type 2 diabetes is a progressive disease that increases in severity with time from diagnosis. The longer an individual has diabetes, the greater the risk of complications that involve the circulatory system or nervous system and that can lead to blindness, amputations, kidney failure, and heart disease (see Chapter 4). So individuals who develop type 2 diabetes in childhood are likely to develop these complications at a younger age. Keeping children's weight in the healthy range and maintaining an active lifestyle can prevent type 2 diabetes.

LDL Cholesterol guidelines for children ages 2 to 19 years

	LDL cholesterol (mg/100 mL)
Acceptable	<110
Borderline	110–129
High	≥130

Orange Line Media/Shutterstock

FIGURE 15.5 Monitoring blood cholesterol in children
The American Academy of Pediatrics recommends blood cholesterol screening for children between the ages of 9 and 11.[13]

Risk of Heart Disease As with adults, poor food choices and inactivity in children increase the risk of developing heart disease. Children in the United States currently consume more than the recommended amount of saturated fat.[11] Many also consume more energy than they expend and participate in less than the recommended amount of activity, leading to overweight or obesity, which contributes to an increase in blood cholesterol and the overall risk of heart disease.[7,12] Elevated blood cholesterol levels during childhood and adolescence are associated with higher blood cholesterol and higher mortality rates from cardiovascular disease in adulthood. The recommended level for LDL cholesterol in the blood of children ages 2 to 19 is less than 110 mg per 100 mL (Figure 15.5).[13]

Hypertension Between 1 and 5% of children and adolescents in the United States have hypertension, and its prevalence has increased over recent decades.[14] The strongest risk factor for hypertension is being overweight or obese. As in adults, an active lifestyle, maintenance of a healthy body weight, and a diet low in sodium and high in whole grains, fruits, and vegetables, with moderate amounts of low-fat dairy products and lean protein sources, are recommended to maintain normal blood pressure.[15] Identification of children with hypertension allows early intervention, which may reduce the long-term adverse health consequences.[14]

Healthy Eating Is Learned for Life

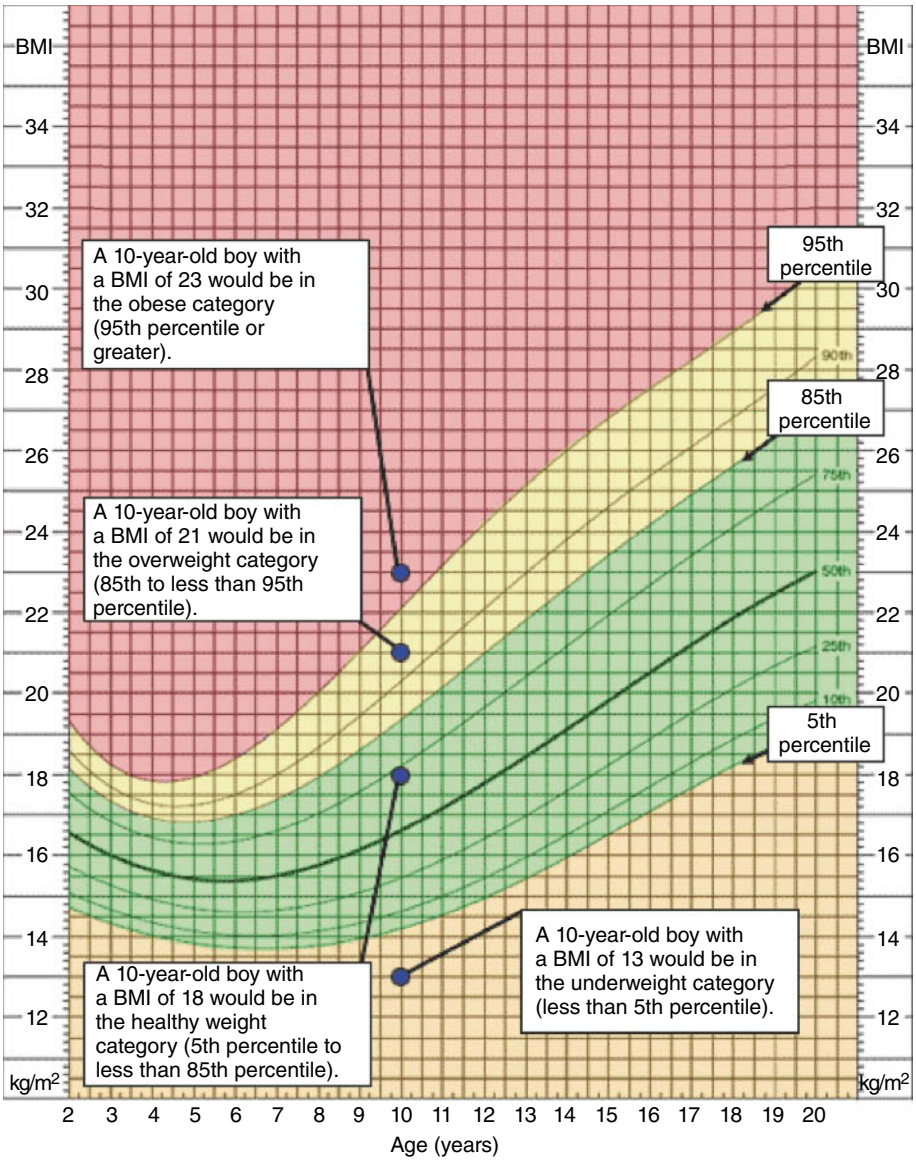
Much of what we choose to eat as adults depends on what we learned to eat as children. Children learn by example, and therefore the eating patterns, attitudes, and feeding styles of their caregivers influence what they learn to eat.[2] When caregivers drink milk, choose whole grains, and eat plenty of fruits and vegetables, children follow their example. Likewise, if a child's role models eat a diet high in fat and low in fruits and vegetables, the child will follow suit. The eating and exercise habits developed during childhood and adolescence are important because they establish a pattern that may last a lifetime and affect how healthy people will be as they get older.

15.2 Nourishing Infants, Toddlers, and Children

LEARNING OBJECTIVES

- Explain why growth is the best indicator of nutrient intake in children.
- Compare the energy and protein requirements of infants and children with those of adults.
- Discuss the recommendations for introducing solid foods to infants.
- Use MyPlate to plan a day's diet that would appeal to an 8-year-old.

Nourishing a growing child is not always an easy task. The foods offered must supply enough energy and nutrients to meet the needs of maintenance, activity, and growth, yet also suit children's tastes. This can be a challenge to caregivers, whether they are feeding infants (ages 4 months to 1 year) sampling solid foods for the first time, toddlers (ages 1 to 3 years) experimenting with new foods, or young children (ages 4 to 8 years) eating meals at school or with friends.



THINK CRITICALLY

If a 10-year-old boy who is obese continues to grow in height but not gain weight, what will happen to his BMI?

FIGURE 15.6 Body mass index-for-age percentiles for boys ages 2 to 20 years
The colored areas represent BMI values associated with underweight, normal or healthy weight, overweight, and obesity in boys. A similar growth chart can be used to assess BMI in girls (see online Appendix E).

Monitoring Growth

The best indicator that a child is receiving adequate nourishment—neither too little nor too much—is a normal growth pattern. If a child does not get enough to eat, growth may be slowed. If intake is excessive, the child is at risk for becoming obese and developing the chronic diseases that are increasingly common in American adults.

The ultimate size (height and weight) that a child will attain is affected by genetic, environmental, and lifestyle factors. A child whose parents are 5 feet tall may not have the genetic potential to grow to 6 feet, but when adequately nourished, most children follow standard patterns of growth. Growth is most rapid in the first year of life, when an infant's length increases by 50%, or about 10 in. In the second year of life, children generally grow about 5 in.; in the third year, 4 in.; and thereafter, about 2 to 3 in./year. During adolescence, there is a period of growth that is almost as rapid as that of infancy. Growth can be monitored using growth charts (see online Appendix E). As discussed in Chapter 14, growth charts for infants were developed by the World Health Organization based on the growth patterns of breast-fed infants living in optimal conditions.[16] For children and adolescents ages 2 to 20 years, weight-for-age, length-for-age, and body mass index (BMI)-for-age growth charts based on typical growth patterns in the United States are available.[17] The BMI-for-age growth chart is recommended for identifying children who are underweight, overweight, or obese (Figure 15.6).

Although growth often occurs in spurts and plateaus, overall growth patterns are predictable. If a child's overall pattern of growth changes, his or her dietary intake should be evaluated to determine the reason for the sudden change. Children who fall below the fifth percentile of the BMI-for-age distribution are considered underweight and their intake should be evaluated

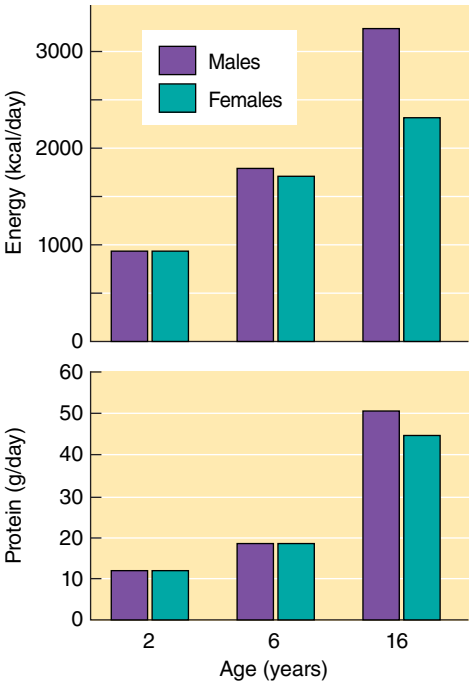


FIGURE 15.7 Total energy and protein needs by age and gender
The total need for both energy and protein increases as children get older.

to be sure they are meeting their needs. Malnutrition during childhood can cause lasting damage for which adequate nutrition later on may not be able to compensate. Children are considered overweight when their BMI is greater than or equal to the 85th percentile and less than the 95th percentile and are considered obese when their BMI is greater than or equal to the 95th percentile (see Figure 15.6). An increase in activity and/or decrease in energy intake may be needed to keep a child's weight in the healthy range.

Nutrient Needs of Infants and Children

As children grow, their nutrient requirements per unit of body weight decrease, but total needs increase because they gain weight and become more active. Recommended nutrient intakes for boys and girls do not differ until about 9 years of age, at which time sexual maturation causes differences in their nutrient requirements.

Energy and Energy-Yielding Nutrients The amount of energy and protein needed per kilogram of body weight decreases with age, but the total amount of each increases as body size increases. The average 2-year-old needs about 1000 kcal and 13 g of protein per day. By age 6, that child will need about 1600 kcal and 19 g of protein per day (Figure 15.7).[18]

Infants need a high-fat diet (40 to 55% of energy intake) to support their rapid growth and development. For this reason, Nutrition Facts labels on foods intended for children younger than 2 years old list total fat but do not list the amounts of saturated and unsaturated fat.[19] It is hoped that limiting the information about fat on the label will prevent caregivers from restricting the amount of fat in the diets of young children. By age 4, the recommended proportion of calories from fat is reduced to provide adequate energy without increasing the risk of developing chronic disease. The acceptable range for fat intake is 30 to 40% of energy for children ages 1 to 3 years and 25 to 35% of energy for those 4 through 18 years of age, compared to 20 to 35% for adults. Children's diets must provide adequate amounts of essential fatty acids; specific AIs have been set for linoleic and α-linolenic acid. To reduce the risk of developing high blood cholesterol levels and subsequent heart disease, the diets of children over the age of 3 should also be low in saturated fat and *trans* fat. Most fats should come from foods rich in polyunsaturated and monounsaturated fatty acids, such as fish, nuts, and vegetable oils.[15]

Carbohydrate recommendations for children are the same as those for adults: 45 to 65% of energy. Specific fiber recommendations have not been made for infants, but an AI has been established for children based on data that show an intake of 14 g of fiber per 1000 kcal reduces the risk of heart disease. As in the adult diet, most of the carbohydrate in a child's diet should be from whole grains, fruits, and vegetables, which are excellent sources of fiber. Fiber supplements are not recommended for children since high intakes can limit the amount of food and, consequently, the nutrients that a small child can consume. Foods high in added sugars, such as cookies, candy, and soda, should be limited.

Water and Electrolytes By 1 year of age, a child's kidneys have matured and the proportion of fluid lost through evaporation has decreased, so total fluid losses decline. As with adults, in most situations drinking enough to satisfy thirst will provide sufficient water. In children 1 to 3 years of age, about 1.3 L (5½ cups) of water daily will meet needs; about 1 L (4 cups) of this should be from water and other fluids. Older children, ages 4 to 8, need about 1.7 L (7 cups) per day.[20] Water needs increase with illness, when the environmental temperature is high, and when activity increases sweat losses.

A UL of 2.3 g of sodium per day has been set for adults and teens 14 to 18 years of age because a high sodium intake is associated with elevated blood pressure. The UL is somewhat lower in children and younger teens (see inside cover). The typical sodium intake in children and teens currently exceeds the UL.[20]

Micronutrients Children are smaller than adolescents and adults, and for the most part the recommended amounts of micronutrients are also smaller (see inside cover). Generally, a nutrient-dense diet that follows the MyPlate recommendations for children will meet needs.

Consuming the recommended amounts of meats and whole and enriched grains helps ensure enough B vitamins. Adequate fruits and vegetables provide vitamin C and vitamin A. Milk provides calcium and vitamins A and D. Fortified breakfast cereals help compensate for poorer diets by providing the recommended amounts of a variety of vitamins and minerals in a single serving. The majority of toddlers and preschoolers in the United States meet recommendations for micronutrient intakes.[21] However, when children's dietary patterns include sugar-sweetened beverages, desserts, and salty snacks, they may be low in nutrient density.[22] When combined with the high nutrient needs and low energy requirements of children, a diet low in nutrient density increases the risk for deficiencies of micronutrients such as potassium, calcium, vitamin D, and iron.

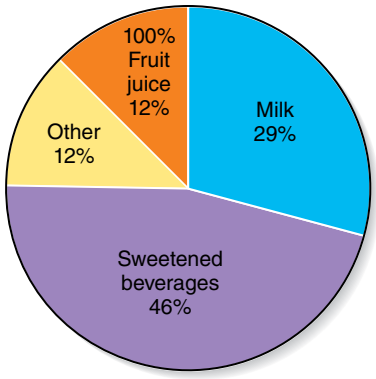


FIGURE 15.8 Beverage choices in children and teens
Consumption of soft drinks by children and adolescents has increased since the 1970s, and milk consumption has decreased. Today, 46% of their beverage intake by weight is soft drinks and other sweetened beverages, while only 29% is milk.[24] This pattern has increased the intake of added sweeteners and decreased the amounts of calcium, phosphorus, magnesium, potassium, protein, riboflavin, vitamin A, and zinc in their diets.

THINK CRITICALLY

Do you think chocolate milk should be categorized as a sweetened beverage? Should it be eliminated from children's diets? Why or why not?

Calcium, Vitamin D, and Bone Health Calcium intake in school-age children has been declining, primarily due to a decrease in the consumption of dairy products (Figure 15.8). Adequate calcium intake during childhood is essential for achieving maximum peak bone mass, which is important for preventing osteoporosis later in life (see Chapter 11). The RDA for calcium is 700 mg/day for toddlers (ages 1 to 3) and 1000 mg/day for young children (ages 4 to 8).[23]

Vitamin D, which is needed for calcium absorption, is also essential for bone health. Low blood levels of vitamin D are problematic in children due to low intake as well as limited synthesis from sunlight in those with dark skin pigmentation or inadequate exposure to sunlight during the winter months.[25] The RDA is 600 IU (15 μg)/day for children, adolescents, and young adults (see **Science Applied: Vitamin D: From Cod Liver Oil to Fortified Milk**). Average intakes for both boys and girls ages 2 to 11 are below the RDA.[26] Increasing milk intake will increase intake of calcium, vitamin D, and potassium.

Iron and Anemia The RDA for iron for infants 7 to 12 months of age is 11 mg/day. This drops to 7 mg/day for toddlers, but for young children ages 4 to 8 it is 10 mg/day, which is higher than the RDA for adult men. Milk is a poor source of iron and is high in calcium, which inhibits iron absorption. Children, especially those ages 1 through 5, who consume large amounts of milk may not consume enough iron to meet their needs. Children in this age group should be limited to no more than 24 oz of milk daily and encouraged to eat good sources of iron, such as fortified grains and breakfast cereals, raisins, eggs, and lean meats, and to consume fruits and vegetables high in vitamin C to promote iron absorption.[27] Iron deficiency can lower resistance to illness and slow recovery time. It can affect learning ability, intellectual performance, stamina, and mood.[28,29] If anemia is diagnosed, iron supplements are usually prescribed until iron stores are replete. Iron supplements should be kept out of the reach of children, because even a single large dose of iron can damage the intestinal lining and cause abnormalities in body pH, shock, and liver failure. Iron toxicity from supplements is one of the most common forms of poisoning among children under age 6 and is the leading cause of liver transplants in children. To protect children from accidental poisoning from iron-containing drugs and supplements, these products display a warning on the label (see Figure 12.6).[30]

Meeting Infants' and Children's Nutrient Needs

The development of nutritious eating habits begins in infancy and childhood. Parents and caregivers influence which foods children learn to eat through the examples they set and the amounts and types of foods offered. Children are more likely to eat foods that are available and easily accessible, and they tend to eat greater quantities when larger portions are provided.[31] Caregivers are responsible for deciding what foods and portions should be offered to a child, when they should

SCIENCE APPLIED

Vitamin D: From Cod Liver Oil to Fortified Milk

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

Rickets, a vitamin D deficiency disease that results in bone deformities, has plagued infants for centuries. Soranus, a late-first-century Roman physician, was one of the first to describe these bone abnormalities in infants.[33] In the 17th century, the English physician Daniel Whistler published the first description of the clinical features and symptoms of this malady. At the beginning of the 20th century, when air pollution from the Industrial Revolution darkened the skies, rickets affected more than 90% of children in Northern Europe and 80% of children in Boston and New York City.[34] At the time, the cause and cure for the disease were unknown.

Mary Evans/Photo Researchers, Inc.

Cod liver oil was marketed as a cure for many ailments in the early 20th century. Today children get their vitamin D from fortified milk rather than a spoonful of cod liver oil.

THE SCIENCE

The relationship between rickets and sunlight did not go unnoticed by scientists. In the late 1800s it was observed that children living in northern European cities such as London and Glasgow were plagued with rickets, while even impoverished children in sunny regions of the world were free of the disease.[34] The idea that sun exposure could help bones seemed preposterous to many, so interest also focused on the curative properties of cod liver oil, which had for centuries been a folk remedy for rickets. When lion cubs at the London Zoo developed rickets in 1889, cod liver oil and crushed bones added to the diet caused a complete recovery.[33] Because cod liver oil was known to be a source of vitamin A, a vitamin A deficiency was proposed as the cause of rickets, and foods rich in vitamin A, such as cod liver oil, butter, and whole milk, were suggested as a remedy. The true anti-rachitic factor was identified in the 1920s by Dr. Elmer McCollum and his colleagues at Johns Hopkins University. They experimented with cod liver oil that had been treated in a way that destroyed the vitamin A. The treated oil was not able to cure vitamin A deficiency, but still retained its ability to cure rickets in rats. They concluded that the anti-rachitic substance found in the oil was distinct from vitamin A and called the substance vitamin D.[33]

A complete understanding of vitamin D and rickets was complicated by the fact that it can be obtained both from the diet and from sunlight, but soon researchers began to recognize that vitamin D was both a nutrient and a hormone. Studies conducted in rodents with experimentally induced rickets demonstrated that rickets could be cured both by exposure to a particular spectrum of ultraviolet light and by supplementation with cod liver oil.[35] Experiments with human infants conducted in Vienna and at Yale University were able to confirm that both exposure to sunlight and the vitamin D in cod liver oil were able to prevent rickets.[33,35]

THE APPLICATION

Understanding the sources and function of vitamin D gave public health officials the tools they needed to eliminate a scourge that had afflicted children since Roman times. By the late 1920s and '30s, public health agencies in the United States were promoting sensible sun exposure, vitamin D supplements, and vitamin D fortification of foods. The use of cod liver oil in the treatment and prevention of rickets became commonplace, and in some states capsules of the oil were distributed to residents. But cod liver oil was not an ideal solution, because people had to remember to take it and some preparations were much lower in vitamin D than others.[36] The solution emerged from the discovery, by Dr. Harry Steenbock at the University of Wisconsin, that irradiating foods and feeding them to rats with rickets cured the rickets.[35] Steenbock's finding led to an inexpensive way to enhance the vitamin D content of foods, including milk. The introduction and consumption of vitamin D–fortified foods led to the virtual eradication of rickets in the United States. People no longer needed to remember to take cod liver oil because science had found a way to put sunshine into their food.

be offered, and where they should be eaten. The child must then decide whether to eat, what foods to eat, and how much of what they are offered to consume.[2] As children get older their choices are affected more by social activities, what they see at school, and what their friends are eating.

Introducing Solid Foods to Infants Although breast milk or infant formula meets most nutritional needs until 1 year of age, semisolid and solid foods can be gradually introduced into the infant's diet starting between 4 and 6 months. Introducing solid foods earlier provides no nutritional or developmental advantages. Despite this, some parents offer semisolid foods before this age, often by adding infant cereal to the baby's bottle because they think the infant is hungry or the added food will help the child sleep through the night. Studies have shown that there is no difference in sleeping patterns based on such feeding practices, and that they may increase the risk of developing food allergies and obesity by preschool age.[32]

Before 4 to 6 months of age, the infant's feeding abilities and gastrointestinal tract are not mature enough to handle foods other than breast milk or formula. The young infant takes milk by a licking motion of the tongue called suckling, which strokes or milks the liquid from the nipple. Solid food placed in the mouth at an early age is usually pushed out as the tongue thrusts forward. By 4 to 6 months of age, the early reflex to bring the tongue to the front of the mouth to suckle has diminished, allowing solid food to be accepted without being expelled. By this age, the infant also can hold his or her head up steadily and is able to sit, either with or without support. Internally, the digestive tract has developed, and enzymes are present for starch digestion. The kidneys are more mature and better able to concentrate urine. With all of these changes, the child is ready to begin a new approach to eating.

What Foods to Introduce First? The most commonly recommended food to be given first to a child is iron-fortified infant rice cereal mixed with formula or breast milk. Rice cereal is the recommended first food because it is easily digested and rarely causes allergic reactions. After rice has been successfully included in the diet, other grains can be introduced, with wheat cereal offered last because it is most likely to cause an allergic reaction. After cereals have been introduced, pureed vegetables or fruits can be tried; some suggest that vegetables be offered before fruits so that the child will learn to enjoy food that is not sweet before being introduced to sweet foods. Once teeth have erupted, foods with more texture can be added (Figure 15.9). For the

FIGURE 15.9 Nourishing a developing infant

	Raul Touzon/NG Image Collection	Andy Lim/Shutterstock	Bubbles Photolibrary/Alamy	Ashok Rodrigues/iStockphoto
Age	Birth to 4 months	4 to 6 months	6 to 9 months	9 to 12 months
Developmental milestones	The infant takes milk from the nipple by suckling. Solid food placed in the mouth is usually pushed out as the tongue thrusts forward.	The tongue is held farther back in the mouth, allowing solid food to be accepted without being expelled. The infant can hold his or her head up and is able to sit, with or without support.	The infant can sit without support, chew, hold food, and easily move hand to mouth.	The infant can drink from a cup and feed him/herself.
Foods	Breast milk or iron-fortified infant formula.	Breast milk or formula, iron-fortified infant cereal; rice cereal is usually the first solid food introduced because it is easily digested and less likely than other grains to cause allergies. After cereals, pureed vegetables and fruits can be introduced.	Breast milk or formula, iron-fortified infant cereal, pureed or strained vegetables, fruits, meats and beans, limited finger foods.	Breast milk or formula, iron-fortified infant cereal, chopped vegetables, soft fruits, meats and beans, fruit juice, nonchoking finger foods such as dry cereal, cooked pasta, and well-cooked vegetables.

TABLE 15.1 Typical Meal Patterns for Infants

	Amounts per day		
	4–6 months	6–9 months	9–12 months
Breast milk or formula[a]	32 oz	32 oz	32 oz
Cereal	4 T infant rice cereal	½ cup Cheerios	½ cup breakfast cereal, rice, or small pasta
Vegetables		4–6 T pureed or baby food	1/3–½ cup cooked vegetables such as peas, diced green beans, or cooked carrots
Fruits		4 T mashed, pureed, or baby food	½ cup soft diced fruits
Meats, fish, poultry, cheese, egg yolk		2–4 T strained or pureed	4–6 T, chopped or ground; ¼ cup cottage cheese
Finger foods		Include finger foods, advancing in size and texture with development: teething biscuits, dry toast, crackers, bananas	Table foods except foods in shapes and sizes likely to cause choking, such as large pieces of meat, whole grapes, or hot dogs or carrots cut in circular slices

[a]Includes formula or breast milk added to cereal.

6- to 12-month-old child, small pieces of soft or ground fruits, vegetables, and meats are appropriate (Table 15.1).

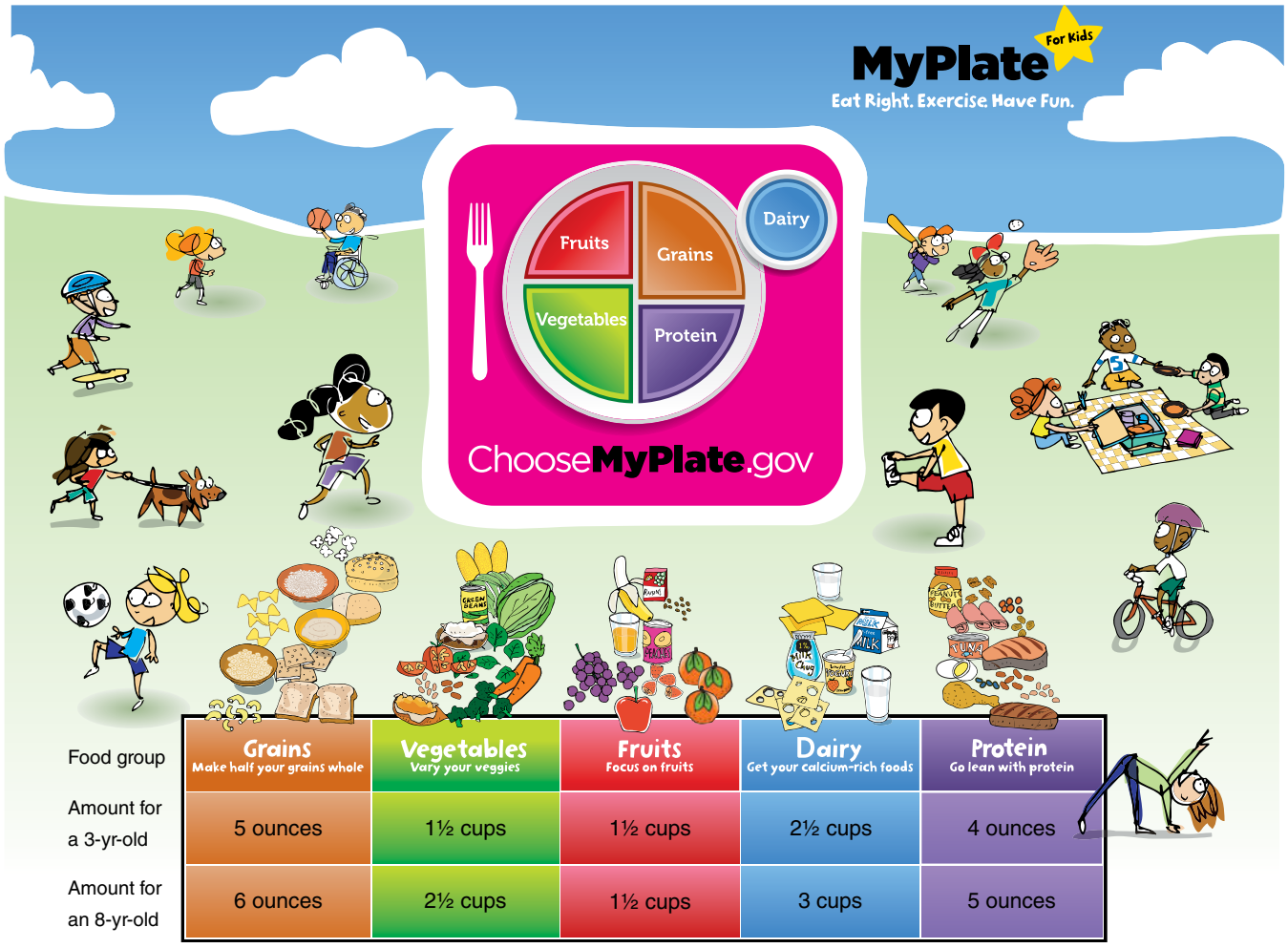
Honey should not be fed to children younger than a year old because it may contain spores of *Clostridium botulinum*, the bacterium that causes botulism poisoning (see Chapter 17). Older children and adults are not at risk from botulism spores because the environment in a mature gastrointestinal tract prevents the bacterium from growing.

Increasing Variety with Developmentally Appropriate Choices As the child becomes familiar with more variety, food choices should be made from each of the food groups in MyPlate. At 1 year of age, whole cow's milk should be offered and continued until 2 years of age, after which reduced-fat milks can be used. Cow's milk should not be used before 1 year of age because it is difficult to digest and the infant's kidneys are too immature to handle its high protein and mineral content. To avoid choking, foods that can easily lodge in the throat, such as carrots, grapes, and hot dogs, should not be offered to infants or toddlers.

As children become more independent, they want to feed themselves. Although this is not always a neat and clean process, it is important for development. By the age of 8 or 9 months, infants can hold a bottle and self-feed finger foods such as crackers. By 10 months, most infants can drink from a cup, so water and fruit juices can be offered (see Figure 15.9). The amount of juice offered to children should be limited. The American Academy of Pediatrics recommends 4 to 6 oz per day of 100% juice for children ages 1 to 6 years, and 8 to 12 oz for children ages 7 and older.[37] More than half the fruit children consume is as juice rather than whole fruit. Although 100% fruit juice can be part of a healthy diet, too much can cause diarrhea, over- or undernutrition, and dental caries. Juice should not be offered to children in containers that can be carried around, encouraging continuous sipping because this increases the risk of dental caries.[15,37]

Developing Healthy Eating Habits in Children Children should be offered a balanced and varied diet adequate in energy and essential nutrients and appropriate to the child's developmental needs. A healthy meal plan is based on whole grains, vegetables, and fruits; is adequate in milk and other high-protein foods; and is moderate in fat and sodium. Following the MyPlate recommendations for children and spreading these amounts throughout the meals and snacks served each day will help meet healthy eating goals (Figure 15.10). For example, a 6-year-old, moderately active boy would only need 5 oz of grains. These could include a half cup of cereal at breakfast, some crackers for a snack, a sandwich at lunch, and a half cup of rice at dinner. This child would need 2½ cups of milk a day, but these may be consumed in smaller portions throughout the day (Table 15.2). The need for nutrient-dense choices from all food groups is just as important for children as it is for adults.

Getting a child to eat all the foods recommended by MyPlate may not always be easy. To increase variety, new foods should regularly be introduced into a child's diet. Children's food preferences are learned through repeated exposure to foods; children develop an increased



Food group	Grains Make half your grains whole	Vegetables Vary your veggies	Fruits Focus on fruits	Dairy Get your calcium-rich foods	Protein Go lean with protein
Amount for a 3-yr-old	5 ounces	1½ cups	1½ cups	2½ cups	4 ounces
Amount for an 8-yr-old	6 ounces	2½ cups	1½ cups	3 cups	5 ounces

FIGURE 15.10 MyPlate for children
MyPlate recommends amounts of food from each group that are appropriate for young children. The recommendations shown here are for a 3-year-old and an 8-year-old girl who engage in more than 60 minutes of activity daily. Food choices to meet these amounts should be spread throughout the meals and snacks served each day.

preference for a food if it is offered a minimum of 8 to 10 times.[2] Children are also more likely to try a new food if it is introduced at the beginning of a meal, when the child is hungry, and if the child sees his or her parents or peers eating it. Incorporating refused foods into familiar dishes can also increase the variety of the diet. If vegetables are refused, they can be added to soups and casseroles. Fruit can be served on cereal or in milkshakes. Cheese can be included in foods such as macaroni and cheese, sandwiches, and pizza. Milk can be added to hot cereal, cream soups, puddings, and custards, and powdered milk can be used in baking. Meats can be added to spaghetti sauce, stews, casseroles, burritos, or pizza.

Children often have periods, known as **food jags**, when they will eat only certain foods and nothing else. For example, a child may refuse to eat anything other than peanut butter and jelly sandwiches for breakfast, lunch, and dinner. The general guideline is to continue to offer other foods along with those the child is focused on. What a child will not touch at one meal, he or she may eat the next day or the next week. No matter how erratic children's food intake may be, caregivers should offer a variety of appropriate healthy food choices at each meal and let their children select what and how much they will eat (Figure 15.11).

food jag When a child will only eat one food item meal after meal.

Vitamin and Mineral Supplements Like adults, children who consume a well-selected, varied diet can meet all their vitamin and mineral requirements with food. In fact, average intakes of most vitamins and minerals for children 2 to 11 years of age meet recommendations.[1] However, children in this age group often do not meet the recommendations for calcium, vitamin D, potassium, and fiber.[2]

TABLE 15.2 A Typical Meal and Snack Pattern for 3- and 8-Year-Old Children

	Amount	
Food	**3-year-old**	**8-year-old**
Breakfast		
Whole-grain cereal	½ cup	1 cup
Milk, 2%	½ cup	½ cup
Banana	½ medium	1 medium
Snack		
Peanut butter	2 T	2 T
Whole-wheat crackers	5	5
Milk, 2%	½ cup	1 cup
Lunch		
Vegetable soup	½ cup	1 cup
Grilled tuna sandwich	½	1
Tomato	¼ medium	½ medium
Orange	½ medium	1 medium
Milk, 2%	½ cup	1 cup
Snack		
Broccoli crowns	4	6
Ranch salad dressing	1 tsp	2 tsp
Dinner		
Chicken drumsticks	1	2
Baked sweet potato	½ cup	1 cup
Green beans	¼ cup	½ cup
Milk, 2%	½ cup	1 cup
Graham crackers	1	2
Snack		
Yogurt	½ cup	1 cup
Berries	½ cup	¾ cup

Occasional skipped meals and unfinished dinners are a normal part of most children's eating behavior. However, children with particularly erratic eating habits, those on regimens to manage obesity, those with limited food availability, and those who consume a vegan diet may benefit from supplements that provide no more than 100% of the Daily Values. To avoid misuse, children's supplements should be stored out of reach and administered by caregivers.

Courtesy Mary Grosvenor

FIGURE 15.11 Food choices
Children should be allowed to select what and how much they will eat from a variety of healthy choices.

How Often Should Meals and Snacks Be Offered? Children have small stomachs and high nutrient needs; therefore, they should consume nutritious meals and snacks throughout the day. For young children, a meal or snack should be offered every two to three hours and, because children thrive on routines and feel secure in knowing what to expect, a consistent pattern should be maintained from day to day. A missed meal or snack can leave a child without sufficient energy to perform optimally at school or play. A healthy breakfast is particularly important for ensuring optimal performance at school.[2] Snacks should be as nutritious as meals and should focus on fruits, vegetables, low-fat dairy products, lean meats, and whole-grain products, not soda and chips (Table 15.3).

TABLE 15.3 Healthy Snacks for Young Children

Focus on Fruit—Make popsicles from fruit juice; cut fruit into interesting shapes; try frozen grapes; make trail mix with raisins, dried cranberries, and other dried fruit.
Vary Your Veggies—Dip baby carrots in ranch dressing, add peanut butter to celery, serve salsa with baked tortilla chips.
Get Your Calcium-Rich Foods—Include milk with after-school cookies, try melted cheese on a tortilla, top some fruit with yogurt, snack on string cheese, make a yogurt and fruit shake.
Make Half Your Grains Whole—Try whole-grain breadsticks or pretzels, have graham crackers instead of cookies, pop some corn.
Go Lean with Protein—Put peanut butter on apple slices or crackers, snack on some turkey slices, roll some black beans into a tortilla, spread hummus on crackers.

Meals at Day Care or School All meals need to contribute to a child's nutrient intake, but parents may have little input into what children eat while at day care or school. Ensuring that meals eaten away from home are nutritious is not easy because there is no guarantee that what is served or brought from home will be eaten. A packed lunch should contain foods the child likes and that do not require refrigeration (even if a refrigerator is available, the child is likely to forget to put the lunch in it). Even the most carefully planned lunch is not nutritious if it is not eaten.

For children who buy their lunch at school, the National School Lunch Program provides low-cost meals designed to meet nutrient needs and promote healthy diets. In 2012, nearly 32 million children participated in the program.[38] While the program has provided meals for over 50 years, the specific requirements for these meals have changed over the years. The Healthy, Hunger-Free Kids Act of 2010 provided a new set of school lunch standards based on the Dietary Guidelines and designed to promote nutrition education by teaching children to make appropriate food choices. Each lunch must include fruits and vegetables, half of the grains offered must be whole, and only low-fat or fat-free milk can be offered. Meals must be low in saturated fat and *trans* fats. The sodium content of meals will be reduced gradually over a 10-year period.[39] Within these guidelines, each school or school district can decide which foods to serve and how they are prepared. Participation in the school lunch program generally improves students' diets (Figure 15.12).

Baerbel Schmidt/Stone/Getty Images, Inc.

FIGURE 15.12 School lunches
Children have responded to the school lunch standards set by the Healthy, Hunger-Free Kids Act of 2010 by eating more fruit, throwing away less of their entree and vegetables, and consuming the same amount of milk as before these standards were implemented.[40]

In addition to lunches, federal guidelines regulate meals provided as part of the School Breakfast Program and foods sold in school vending machines. Vending machine snacks must have fewer than 200 kcal, less than 230 mg of sodium, less than 35% of calories from fat, and less than 35% of their weight from sugar. The only beverages that can be sold in vending machines are water, low-fat and fat-free milk, fruit and vegetable juices, and fruit and vegetable juices diluted with water but containing no sweeteners.[39]

Eating Environment Factors such as whether families eat together, watch TV during meals, and choose food prepared at home or at a restaurant influence children's eating patterns.[2] To develop sound eating habits, children need companionship, conversation, and a pleasant location at mealtimes. Caregivers should sit with children and eat what they eat (Figure 15.13). Children should be given plenty of time to finish eating. Slow eaters are unlikely to finish eating if they are abandoned by siblings who run off to play and adults who leave to wash dishes.

To make mealtime a nutritious, educational, and enjoyable experience, it should not be a battle zone. Threats and bribes are counterproductive and can create a problem where none had previously existed. Food is not a reward or a punishment: It is simply nutrition.

Masterfile

FIGURE 15.13 Family meals
Companionship and conversation at meals help create a positive eating environment and foster good eating patterns.

15.3 Nutrition and Health Concerns in Infants and Children

LEARNING OBJECTIVES

- Summarize the recommendations for preventing and managing food allergies.
- Discuss the relationship between food intake patterns and dental caries.
- Describe the impact of the modern American lifestyle on childhood obesity.
- Discuss the recommendations for preventing and treating childhood obesity.

A number of diet and lifestyle factors put children at risk for illness and malnutrition. Some are a greater risk in young children because of their size and stage of development and others are problems that may continue into adolescence and adulthood.

Food Allergies and Intolerances

Most food allergies develop during infancy, when the immature digestive tract allows incompletely digested dietary proteins to be absorbed. In susceptible individuals, exposure to these food allergens for the first time causes the immune system to produce antibodies to that allergen (see Chapters 3 and 6). When the allergen is encountered again by eating the same food, symptoms such as vomiting, diarrhea, asthma, hives, eczema, runny nose and swelling of respiratory tissues, hay fever, and general cramps and aches may result as the immune system battles the allergen.[41] The symptoms may occur almost immediately or take up to 24 hours to appear, and can vary from mild to severe and life threatening. Foods that commonly cause allergies include wheat, peanuts, eggs, milk, nuts, fish, shellfish, and soy.

To monitor for food allergies when solid foods are given to infants, it is important to introduce new foods one at a time. Each new food should be offered for a few days without adding any other new foods. If an allergic reaction occurs, it is most likely due to the newly introduced food. Foods that cause allergy symptoms such as rashes, digestive upsets, or respiratory problems should be discontinued before any other new foods are added. After an infant is about 3 months of age, the risk of developing food allergies is reduced because incompletely digested proteins are less likely to be absorbed. Some food allergies that develop before the age of 3 years will be outgrown. For example, most children allergic to eggs at 1 year of age are no longer allergic by age 5.[41] Other allergies continue throughout life.

Adverse reactions to foods are also caused by food intolerances. In contrast to food allergies, food intolerances do not involve antibody production by the immune system. Rather, they are caused by foods that create problems during digestion. Food intolerances can be caused by chemical components in foods, by toxins that occur naturally in foods, by substances added to foods during processing or preparation, or simply by large amounts of foods, such as onions or prunes, that cause local gastrointestinal irritation. Lactose intolerance is an example of a food intolerance caused by a reduced ability to digest milk sugar. It is not an allergy to milk proteins.

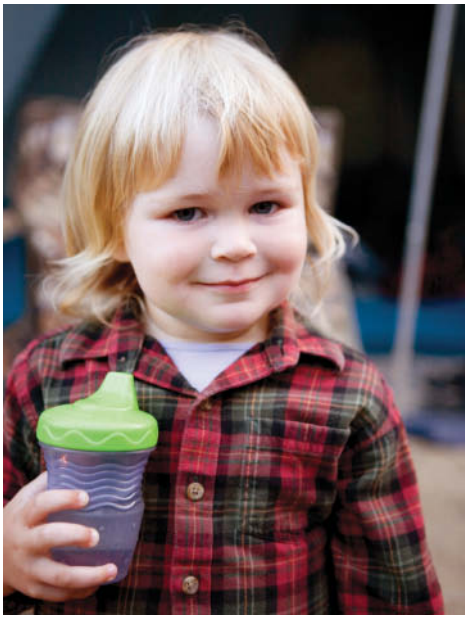
elimination diet and **food challenge** A regimen that eliminates potential allergy-causing foods from an individual's diet and then systematically adds them back to identify any foods that cause an allergic reaction.

Diagnosing Food Allergies Several laboratory methods are available to identify foods that are likely to cause an individual's allergic reaction, but they cannot determine the source of the problem with 100% reliability. The cause of a food allergy can be confirmed by using an **elimination diet** and **food challenge**. This involves eliminating all foods suspected of causing an allergic reaction from the diet. Once a diet that causes no symptoms has been established, it should be

consumed for two to four weeks. Then, in the food challenge, small amounts of a food suspected of causing a reaction are reintroduced under a doctor's supervision. If no reaction to the food occurs, then increasing amounts are introduced until a normal portion is offered. If there is still no reaction, then the food can be ruled out as an allergen.[41]

Preventing and Managing Food Allergies Preventing the development of food allergies is not always possible. Breast-feeding can reduce the risk of food allergies and is recommended for infants from families with a history of allergies.[42] Infants who are breast-fed are less likely to be exposed to foreign proteins that cause food allergies. In addition, their gut matures earlier and they are protected by antibodies and other components of human milk. There is no evidence that delaying the introduction of solid food, including foods thought to be highly allergenic, past 6 months protects against the development of food allergies.[43]

Once a food allergy has developed, the best way to manage it is to avoid consuming the offending food. The information on food labels can be helpful in identifying foods that contain allergy-causing ingredients (see Chapter 6, *Off the Label: Is It Safe for You?*).



Tim Laman/NG Image Collection

FIGURE 15.14 Limiting sweetened beverages
Offering beverages that can be carried around encourages continuous sipping and is not recommended. When juice is sipped slowly over a long period, it provides a continuous supply of sugar to feed cavity-causing bacteria.[15,37]

Dental Caries

Children typically eat more sugar than is recommended. Added sugars reduce the nutrient density of foods, so excessive consumption of foods high in added sugars makes it difficult to meet nutrient needs. In addition, a diet high in sugary foods promotes the growth of bacteria on the surface of the teeth, increasing the risk of dental caries, commonly known as tooth decay or cavities. Decay occurs when bacteria metabolize sugar, producing acids, which damage the structure of the teeth. Because the primary teeth guide the growth of the permanent teeth, maintaining healthy primary teeth is just as important as preserving permanent ones.

Much of the added sugar in children's diets comes from soft drinks and other sweetened beverages; when these are sipped slowly between meals, the contact time between sugar and teeth is prolonged, hence increasing the risk of tooth decay (Figure 15.14). Changing the types of beverages consumed by children may impact the incidence of dental caries. A study found fewer cavities in children who drank more milk and more in those who consumed soda and juice.[44] All carbohydrate-containing food can cause tooth decay, but sugary foods—especially those that stick to the teeth—are the most cavity-promoting type (see Chapter 4).

Both diet and dental hygiene can affect the risk of dental caries. Preventing tooth decay involves limiting high-carbohydrate snacks, especially those that stick to teeth; brushing teeth frequently to remove sticky sweets; and consuming adequate fluoride. It is recommended that children consume three servings of dairy foods daily, limit intake of 100% juice, and restrict sugar-sweetened beverages to occasional treats.[37,44] Children's teeth should be brushed as soon as they erupt and children 3 years of age and older should be examined by a dentist regularly.

Diet and Attention Deficit/Hyperactivity Disorder

Five to 10% of school-age children have been diagnosed with **attention deficit/hyperactivity disorder (ADHD)**; it occurs more frequently in boys than in girls.[45] ADHD involves extreme physical activity, excitability, impulsiveness, distractibility, short attention span, and low tolerance for frustration. Children with ADHD have more difficulty learning, but usually are of normal or above-average intelligence.

attention deficit/hyperactivity disorder (ADHD) A condition characterized by a short attention span, acting without thinking, and a high level of activity, excitability, and distractibility.

Although parents of children with ADHD report a worsening of symptoms after excessive ingestion of candy or soda, controlled studies have not found sugar intake to affect children's

behavior or cognitive performance.[46] It has been suggested, however, that reactive hypoglycemia following sugar ingestion may contribute to inattention and cognitive impairment in children with ADHD. In some children, the hyperactive behavior observed after sugar consumption may be the result of situational factors. For example, the excitement of a birthday party rather than the sugar in the cake may be what affects behavior.

One cause of hyperactive behavior in children is caffeine. Caffeine is a stimulant that causes sleeplessness, restlessness, and irregular heartbeats. Beverages, foods, and medicines containing caffeine are often part of children's diets. For example, caffeinated beverages such as Coke and Mountain Dew are commonly included in children's fast-food meals.

Other possible causes of hyperactivity include lack of sleep, overstimulation, desire for more attention, or lack of physical activity. Specific foods and food additives have also been implicated as causes of hyperactivity. Numerous studies have failed to provide sufficient evidence for the efficacy of any dietary treatment for ADHD. However, some children are sensitive to specific additives and may benefit from a diet that eliminates them.[46]

Lead Toxicity

Lead is an environmental contaminant that can be toxic, especially in children under age 6. Children can be exposed to lead in air pollution, old house paint, lead plumbing, and certain ceramics. Children are at particular risk for lead toxicity because they absorb lead much more efficiently than do adults. Malnourished children are at even greater risk because malnutrition increases lead absorption due to the fact that lead is better absorbed from an empty stomach and when other minerals such as calcium, zinc, and iron are deficient. Once it has been absorbed from the gastrointestinal tract, lead circulates in the bloodstream and then accumulates in the bones and, to a lesser extent, the brain, teeth, and kidneys. Lead disrupts the functioning of neurotransmitters and thus interferes with the functioning of the nervous system.

In young children, lead poisoning can affect IQ and cause both learning disabilities and behavior problems. High levels of lead can contribute to iron deficiency anemia, changes in kidney function, nervous system changes, and even seizures, coma, and death. No safe blood lead level has been identified. About half a million U.S. children have blood lead levels above the reference level of 5 μg/100 mL.[47] Medical treatment is recommended for children with blood lead levels greater than or equal to 45 μg/100 mL.

Because of the risks of lead toxicity from environmental contamination, state legislatures began to prohibit the use of lead in house paint, gasoline, and solder. As a result, the number of children ages 1 to 5 with elevated blood lead levels has decreased dramatically.[48] Despite these gains, low-income children remain at higher risk because low-income families are more likely to live in older buildings that still have lead paint and lead plumbing. Typical blood lead levels for non-Hispanic black children remain slightly higher than those for Mexican American and non-Hispanic white children, in part reflecting differences in socioeconomic status.[49]

Childhood Obesity

As discussed previously, childhood obesity is a major public health problem.[7] It not only increases health risks during childhood but also in the long term; individuals who are overweight or obese as children are more likely to develop heart disease, diabetes, arthritis, and cancer as adults.[50] Reducing the incidence of childhood overweight and obesity requires changes in lifestyle.

How Television Affects Body Weight Many children today spend more time watching television than they do in any activity other than sleep. Television affects nutritional status in a number of ways: It introduces children to foods they might otherwise not be exposed to, it promotes snacking, and it reduces physical activity. More television watching is associated with an increase in calorie intake and body fatness among children (see **Critical Thinking: Undernutrition May Accompany Overnutrition**).[2]

Through advertising, television has a strong influence on the foods selected by young children; children exposed to advertising choose advertised food products more often than children who are not exposed.[51] Food is the most frequently advertised product category on children's TV. The majority of these ads target products high in fat, sodium, and added refined sugars, such as

CRITICAL THINKING

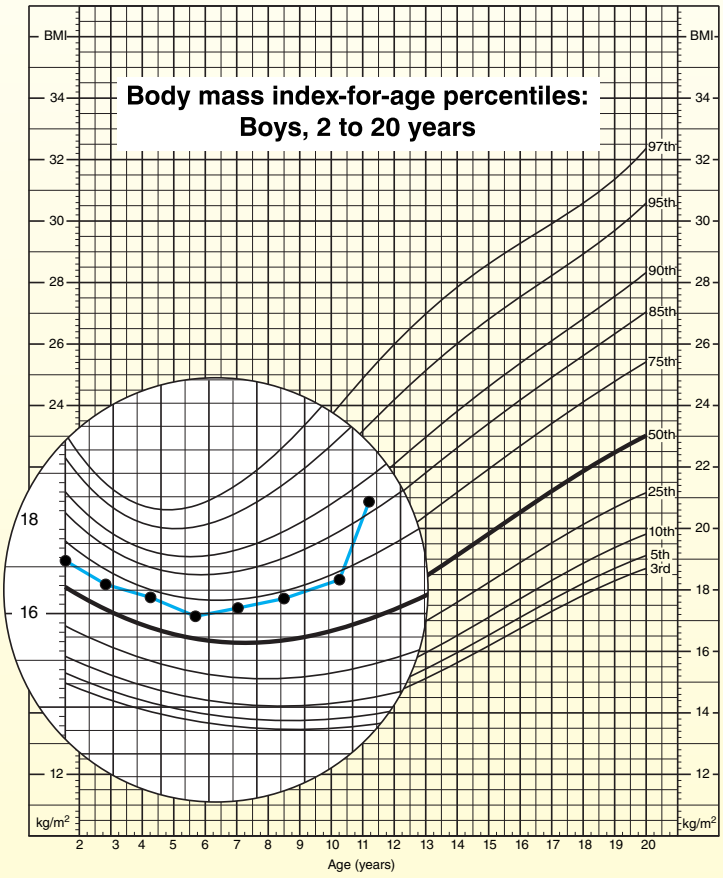
Undernutrition May Accompany Overnutrition

© 5PH / Shutterstock

Sam is 8 years old and has gained 5 lb in the past three months. His parents are worried because all Sam wants to do is watch TV. Because Sam's parents are both overweight, they are concerned that he will also have a weight problem, so they take him to see his pediatrician.

Based on this growth chart, how has Sam's BMI percentile changed during the past year?

CDC Growth Charts: United States



Reviewing Sam's diet and exercise patterns, the doctor learns that Sam has been watching TV or playing video games for about six hours a day. He eats donuts and milk for breakfast, gets lunch from the school lunch program, and then snacks on chips and soda when he gets home from school. He drinks about five glasses of whole milk a day.

What nutrients are likely to be excessive or deficient in this dietary pattern?

A blood test reveals that Sam has iron deficiency anemia. The pediatrician prescribes an iron supplement and refers Sam and his parents to a dietitian. She recommends that the family switch to 1% milk to reduce Sam's energy and saturated fat intake and to a fortified cereal for breakfast to increase his iron intake. She also recommends that they limit Sam's after-school snacking to fruit so he can eat a better evening meal.

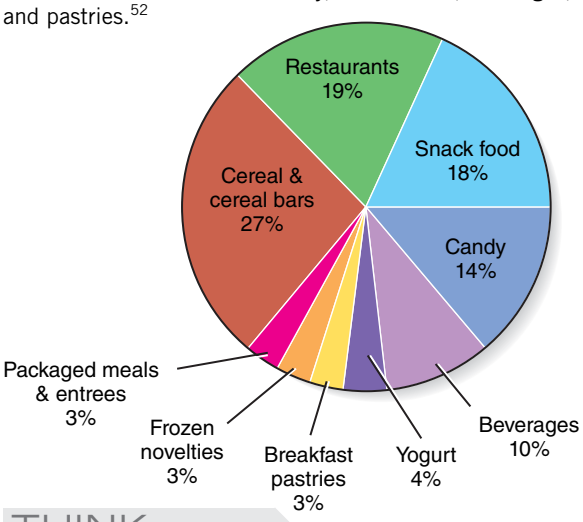
iProfile Use iProfile to find snack choices that are nutrient dense and filling, but still low in calories.

CRITICAL THINKING QUESTIONS

- **Sam needs to increase his activity to avoid further weight gain. What activity recommendations would you make for Sam?**
- **Why might excessive consumption of dairy products contribute to Sam's anemia?**
- **How might Sam's iron deficiency have contributed to his weight gain?**

FIGURE 15.15 Television affects food intake and activity level

A. During children's television programming, food is the most frequently advertised product category. This chart, which illustrates the types of food advertised on Saturday morning children's television, shows that almost half of the commercials advertise candy, snack foods, beverages, and pastries.[52]



Donna Day/Getty Images, Inc.

B. Watching television is a sedentary pastime. More time watching TV is associated with a higher BMI among children and adolescents.[54]

THINK CRITICALLY

Should the types of advertising allowed on children's TV be regulated?

sweetened breakfast cereals, doughtnuts, candy, cookies and other desserts, snack foods, sweetened beverages, and fast-food (Figure 15.15A).[52] The more hours of TV a child watches, the more he or she asks for advertised food items and the more likely these items are to be in the home.[53] Television also promotes snacking behavior. Although snacks are an important part of a growing child's diet, while watching TV many children snack on sweet and salty foods that are low in nutrient density.

Perhaps the most important way television impacts nutritional status is by reducing activity (Figure 15.15B). Hours spent watching television are hours when physical activity is at a minimum. Generally the more physically active a child is, the less TV he or she watches. Children and adolescents today have replaced physically demanding activities with sedentary pastimes including watching television, playing video games, and networking on cell phones and computers. It is recommended that children limit television and other screen activities to no more than 1 to 2 hours per day.[13]

Robert Ginn/Photolibrary/Getty Images, Inc.

FIGURE 15.16 Fast food
Consuming too much fast food and making poor fast-food choices can result in a diet high in calories and low in fruits, vegetables, whole grains, and dairy products.

How Fast Food Impacts Energy and Nutrient Intake Children and teens generally love fast food, and there is nothing wrong with an occasional fast-food meal. But a steady diet of burgers, fries, and soda will likely contribute to an overall diet that is high in energy, fat, sugar, and salt and low in calcium, fiber, and vitamins A and C (Figure 15.16).

The portions served at fast-food restaurants are a major contributor to children's increased energy intake. A meal that includes a hamburger, small fries, and a small drink will provide about 600 kcal, 12 g of saturated fat, and 36 g of sugar. But a meal with a Big Mac, a large order of fries, and a large drink will increase the numbers to about 1400 kcal, 15 g of saturated fat, and 94 g of sugar. A steady diet of such meals can significantly increase energy intake and consequently body weight. Choosing carefully from the old fast-food standbys such as plain, single-patty hamburgers or newer low-fat options such as grilled chicken sandwiches can keep fat and energy intake reasonable (Table 15.4).

Some food groups are limited in typical fast-food meals. For example, the few pieces of shredded lettuce and the slice of tomato that garnish a burger or taco make only a small contribution to the 2½ cups of vegetables that should be included in the diet of an average 8-year-old. Typically, fast-food meals are also lacking in milk, fruit, and whole grains.[2] Many fast-food franchises now offer vegetables, salads, yogurt, fruit, and milk, which are moderate in calories and can increase calcium and vitamin intake if selected. Even if these foods are not chosen, if the missing milk, fruits, vegetables, and whole grains are consumed at other times during the day and overall energy intake balances output, the total diet can still be a healthy one.

TABLE 15.4 Make Healthier Fast-Food Choices

Instead of . . .	Choose . . .
Double-patty hamburger with cheese, mayonnaise, special sauce, and bacon	Regular single-patty hamburger with ketchup and mustard
Breaded and fried chicken sandwich	Grilled chicken sandwich
Chicken nuggets or tenders	Grilled chicken strips
Large order of French fries	Baked potato, side salad, or small order of fries
Fried chicken wings	Broiled skinless wings
Crispy-shell chicken taco with extra cheese and sour cream	Grilled-chicken soft taco with salsa
Nachos with cheese sauce	Tortilla chips with bean dip
12-in. meatball sub	6-in. turkey breast sub with lots of vegetables
Thick-crust pizza with extra cheese and meat toppings	Thin-crust pizza with extra veggies

Reducing the Incidence of Obesity Reducing the incidence of childhood overweight/obesity requires changes in eating behavior and activity patterns. The goal is to promote healthy body weight in all children and help children who are overweight or obese to stop gaining weight or slowly lose weight.

To prevent childhood obesity, the Institute of Medicine's Committee on Prevention of Obesity in Children and Youth recommends involvement of federal, state, and local governments; industry and the media; health-care professionals; community and nonprofit organizations; schools; and parents and families.[55] The committee's report suggests that the food, beverage, restaurant, entertainment, leisure, and recreation industries help encourage healthy, appropriately portioned foods and develop products and opportunities that stimulate physical activity. The report also recommends changes in the food label and the development of advertising and marketing guidelines that help minimize the risk of obesity. At the community level, recommendations focus on programs that encourage healthy eating behaviors and regular exercise by providing children with safe places to walk, bike, play games and sports, and engage in other physical activities. The report targets schools because they are a place where children can be reached with information about energy balance, good nutrition, and physical activity. Schools can offer foods and beverages that meet nutritional standards. In addition, children should achieve at least 60 minutes of physical activity daily.[56] These recommendations apply at home as well as at school because parents make daily decisions regarding food choices and opportunities for recreation, they determine the setting for foods eaten in the home, and they are responsible for other rules and policies that influence the extent to which various members of the family engage in healthful eating and physical activity.

For those who are already overweight, the intensity of the weight management program depends on the child's weight category and the health risks that he or she has.[57] For overweight children at low risk, weight loss is not recommended; rather, weight gain should be slowed while they continue to grow taller. This allows them to "grow into" their weight. A child who is at the 85th percentile for BMI at age 7 and gains only a few pounds a year can be at the 75th percentile by age 9. For children in the obese BMI range, programs should be designed to promote slow weight loss of no more than 1 lb per month for children ages 2 to 5 and no more than 2 lb per week for older children and adolescents. Any weight management program should include reduced intake, increased activity, and behavior change. For severely obese youths (BMI $>$ 99th percentile) for whom these techniques have not been successful, weight loss medications and/or surgery may be recommended.[57]

Reducing Intake Modifying a child's food consumption patterns can be difficult. Denying food may promote further overeating by making the child feel that there will not be enough to satisfy hunger. The child may then overeat whenever there is a chance. Thus, energy intake restrictions should be relatively mild, and the focus instead should be on offering nutrient-dense foods such as whole grains, fruits and vegetables, lean meats, and reduced-fat dairy products. Planning ahead can help manage eating at social events. For example, a teenage girl with a weight problem could plan how much she will eat at a pizza party and then increase her exercise to compensate for the excess calories consumed.

FIGURE 15.17 Meeting activity goals
Exercise should be fun. Riding bikes, using skateboards, and playing basketball and Frisbee all count toward fulfilling exercise goals.

Masterfile

Exercise Guidelines for Children and Adolescents[56]

- Children and adolescents should do 60 minutes or more of physical activity daily.
  - Aerobic: Most of the 60 or more minutes a day should be either moderate- or vigorous-intensity aerobic physical activity, and should include vigorous-intensity physical activity at least 3 days a week.
  - Muscle-strengthening: As part of their 60 or more minutes of daily physical activity, children and adolescents should include muscle-strengthening physical activity on at least 3 days of the week.
  - Bone-strengthening: As part of their 60 or more minutes of daily physical activity, children and adolescents should include bone-strengthening physical activity on at least 3 days of the week.
- It is important to encourage young people to participate in physical activities that are appropriate for their age, that are enjoyable, and that offer variety.

Increasing Activity Whether or not a child is overweight, he or she should be physically active for at least an hour per day.[56] Children have short attention spans, so their activities should be intermittent. Periods of moderate to vigorous activity lasting 10 to 15 minutes or more each day should be interspersed with periods of rest and recovery. Children and adolescents should be exposed to a variety of different types of activities that are of various levels of intensity and include both muscle-strengthening and bone-strengthening activities (Figure 15.17). Learning to enjoy sports and exercise in childhood will set the stage for an active lifestyle in adulthood. For inactive children, physical activity should be increased gradually in order to make exercise a positive experience. A good way to start is to encourage activities such as games, walks after dinner, bike rides, hikes, swimming, and volleyball that can be enjoyed by the whole family. This sends a positive message to "be more active." Again, involvement of the whole family is key to increasing activity.[58]

Changing Behavior As in adults, weight gain in children is related to patterns of eating and activity. Any permanent change in weight requires a permanent change in lifestyle. Because children, like adults, may overeat for comfort, self-reward, or out of boredom, parent involvement in helping the child find other sources of gratification can be vital.

15.4 Adolescents

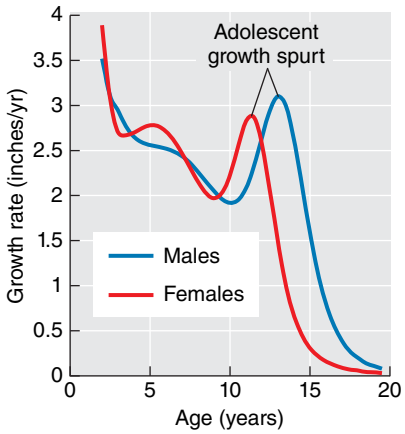
LEARNING OBJECTIVES

- Describe how growth and body composition are affected by puberty.
- Compare the energy needs of adolescents with those of children and adults.
- Explain why iron and calcium are of particular concern during the teen years.
- Use MyPlate to plan a day's diet that would appeal to a teenager.

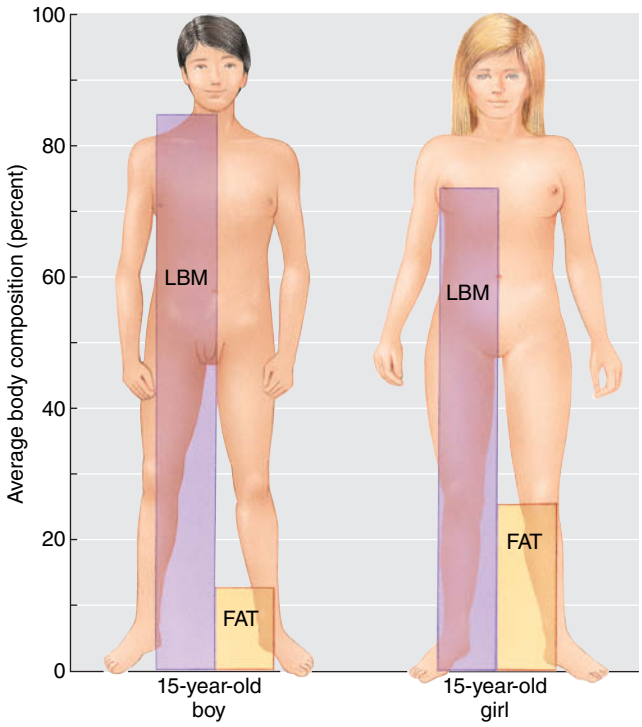
FIGURE 15.18 Adolescent growth

THINK CRITICALLY

How do the differences in the energy and protein needs of boys and girls shown in Figure15.7 relate to the changes that occur in lean body mass at puberty?



A. The adolescent growth spurt begins at about ages 10 to 13 in girls and ages 12 to 15 in boys. During a one-year growth spurt, boys can gain 4 in. in height and girls 3.5 in.



B. After puberty, males have a higher percentage of lean body mass (LBM) and less body fat than females.[60]

Once a child has reached about 9 to 12 years of age, the physical changes associated with sexual maturation begin to occur. These physical changes, along with the social and psychological changes that accompany them, have a significant impact on the nutritional needs and nutrient intakes of adolescents. The DRIs divide recommended intakes for adolescence into ages 9 through 13 and ages 14 through 18.

The Changing Body: Sexual Maturation

During adolescence, organ systems develop and grow, **puberty** occurs, body composition changes, and the growth rates and nutritional requirements of boys and girls diverge. During the teenage years, boys and girls grow about 11 in. and gain about 40% of their eventual skeletal mass. From ages 10 to 17, girls gain about 53 lb and boys about 70 lb. During adolescence, there is an 18- to 24-month period of peak growth velocity, called the **adolescent growth spurt** (Figure 15.18A).

The hormonal changes that occur with sexual development orchestrate growth and affect body composition. During the growth spurt, boys tend to grow taller and heavier than girls and do so at a faster rate. Boys gain fat, but also add so much lean mass as muscle and bone that their percentage of body fat actually decreases (Figure 15.18B). In girls, **menarche**, the onset of menstruation, is typically followed by a deceleration in growth rate and an increase in fat deposition. By age 20, females have about twice as much adipose tissue as males and only about two-thirds as much lean tissue.

Nutrient intake during childhood and adolescence can affect sexual development. Nutritional deficiencies can cause poor growth and delayed sexual maturation. Taller, heavier children usually enter puberty sooner than shorter, lighter ones.[59]

puberty A period of rapid growth and physical changes that ends in the attainment of sexual maturity.

adolescent growth spurt An 18- to 24-month period of peak growth velocity that begins at about ages 10 to 13 in girls and ages 12 to 15 in boys.

menarche The onset of menstruation, which occurs normally between the ages of 10 and 15 years.

Nutrient Needs of Adolescents

The physiological changes that occur during adolescence affect nutrient needs. Total nutrient needs are greater during adolescence than at any other time of life. Because of the large individual variation in the age at which these growth and developmental changes occur, the stage of maturation is

often a better indicator of nutritional requirements than actual chronological age. The best indicators of adequate intake are satiety and growth that follows the curve of the growth charts.

Energy and Energy-Yielding Nutrients The proportion of energy from carbohydrate, fat, and protein recommended for adolescents is similar to that of adults, but the total amount of energy needed by teenagers exceeds adult needs. Energy requirements for boys are greater than those for girls because boys have more muscle and a greater body size. Adolescent girls need 2100 to 2400 kcal/day, whereas boys require about 2200 to 3150 kcal/day (see Figure 15.7). Protein requirements for both groups reach the adult recommendation of 0.8 g/kg/day by about age 19, but since boys are generally heavier, they require more total protein than girls. These higher requirements for males continue throughout life.

Micronutrients The requirements for many vitamins and minerals are greater during adolescence than childhood. Some of these are increased because of increased energy needs and others are increased because of their roles in growth and maturation.

Vitamins The need for most of the vitamins rises to adult levels during adolescence. The requirement for B vitamins, which are involved in energy metabolism, is much higher in adolescence than in childhood because of higher energy needs. The rapid growth of adolescence further increases the need for vitamin B_6, which is important for protein synthesis, and for folate and vitamin B_{12}, which are essential for cell division. In general, the fact that teens have high energy needs allows them to meet most of their vitamin needs because eating more food provides more vitamins. However, vitamin D intake is frequently low in teens' diets, especially in those of girls, possibly due to low milk intake. Low vitamin D intake results in low blood levels when synthesis from sunlight is limited due to dark skin pigmentation or inadequate exposure to sunlight during the winter months. Vitamin D is important to support the rapid skeletal growth that occurs during adolescence (see Chapter 9).[61] Vitamin D deficiency is more prevalent in teens who are overweight or obese than in healthy-weight teens, and the prevalence is even greater in minority teens who are obese.[62]

Calcium During the adolescent growth spurt, both the length and the mass of bones increase. Adequate calcium is essential to form healthy bone. Calcium retention varies with growth rate, with the fastest-growing adolescents retaining the most calcium. The RDA for calcium during adolescence is 1300 mg/day for everyone between the ages of 9 and 18, but intake is typically below this amount in both genders.[23] Typical intake for boys in this age range is 1260 mg/day and for girls 948 mg/day.[63] Calcium intake below the RDA, in combination with a sedentary lifestyle in childhood and adolescence, can impede skeletal growth and bone mineralization and increase the risk of developing osteoporosis later in life.

Foods common in the teen diet that are good sources of calcium include milk, yogurt and frozen yogurt, ice cream, and cheese added to hamburgers, nachos, and pizza. Although milk and cheese are the biggest sources of calcium in teen diets, they can be high in saturated fat, so adolescents should be encouraged to consume reduced-fat dairy products and vegetable sources of calcium. One factor that has contributed to low calcium intake among teens is the use of soda and other sugar-sweetened beverages, rather than milk (Figure 15.19). In addition to providing calcium, milk is an important source of vitamin D, phosphorus, magnesium, potassium, protein, riboflavin, vitamin A, and zinc. Adolescent girls are likely to drink less milk in order to cut calories, favoring low-calorie soft drinks (see **Debate: Will Banning Soda from Schools Reduce Obesity?**).

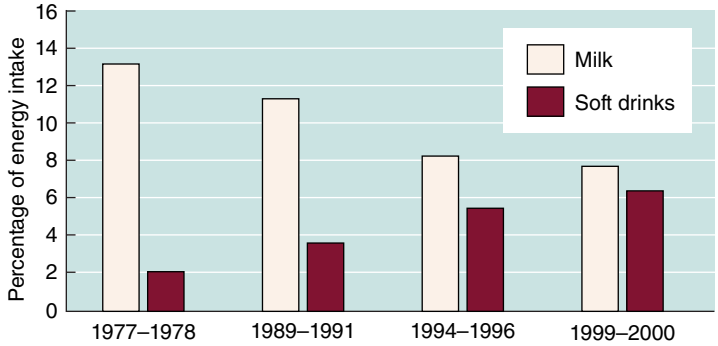


FIGURE 15.19 Percentage of energy from milk and soft drinks[24]
Since the 1970s, children and teens (ages 2 to 18) have more than doubled the number of calories they consume from soft drinks, while cutting the calories they obtain from milk by 34%.

DEBATE

Will Banning Soda from Schools Reduce Obesity?

Obesity is a complex and growing crisis among children in the United States. One factor believed to contribute to childhood obesity is consumption of sugar-sweetened beverages, especially soda.[15] To comply with the Healthy, Hunger-Free Kids Act of 2010, middle and elementary schools must limit beverages sold to water, low-fat and fat-free milk, and 100% fruit and vegetable juices. High schools may also sell low-calorie carbonated beverages.[39] Will this have an impact on the incidence of childhood obesity?

Supporters of a soda ban stress that eliminating sugar-sweetened beverages at school is an important step toward improving children's food environment and health. They point out that these beverages add empty calories and often caffeine to the diet and are linked to obesity and a variety of other health problems. There is evidence that children who drink more sugar-sweetened beverages have greater body weights than those who drink less and that limiting soda consumption contributes to a modest amount of weight reduction.[67,68] Soda consumption also increases the risk of osteoporosis by displacing milk and thus reducing calcium intake. It also contributes to dental caries by providing a supply of sugar to bacteria in the mouth.[15,69]

No one will argue the fact that soda is bad for America's youth, but many contend that removing soda from schools will do little to decrease consumption, promote healthy diets, or reduce obesity. School is only one source of the beverages consumed by children. Limiting the sale of soda in the schools will reduce in-school access to sugar-sweetened beverages, but may not significantly reduce overall consumption.[70] It has been suggested that being deprived of these beverages in school may even encourage children to drink more when they leave school. To have an effect on the overall diet, intake of these beverages at home and at fast-food restaurants must also be limited.

A problem with banning the sale of soda and other sugar-sweetened beverages is that these purchases generate revenue for schools. This money is used for everything from textbook purchases to funding extracurricular activities such as sports programs, field trips, and proms. Some argue that eliminating this source of revenue would result in cuts in sports programs and actually contribute to obesity by reducing physical activity. Supporters of the ban say that revenue should not be generated at the expense of children's health. They point out that schools would never consider selling cigarettes to raise money, so why would they promote soda sales?

Paul J. Richards/NewsCom

Everyone will agree that just banning soda will not solve the obesity epidemic, but that schools can be part of the solution.[71] Schools can promote healthy eating by providing nutrition education and a healthy food environment. Skeptics point out that removing soda does nothing to educate children about healthy diets and lifestyle, and some believe it actually could undermine children's ability to learn how to make healthy decisions for themselves. Despite this criticism about government regulations, evidence is accumulating that more stringent school nutrition standards may lead to a decline in obesity.[72,73]

THINK CRITICALLY: Do you think banning the sale of sugar-sweetened beverages in schools will reduce children's sugar consumption? Why or why not?

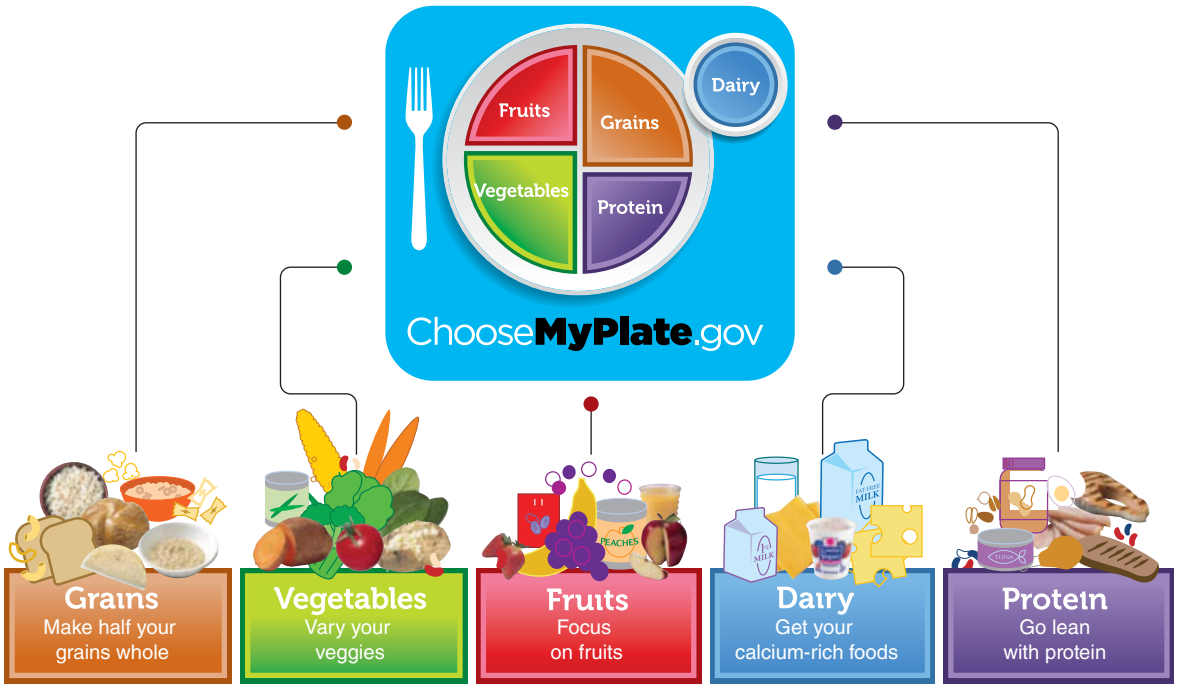
Iron Iron deficiency is common in adolescent females, affecting about 9% of girls ages 12 to 15 and 16% of young women ages 16 to 19.[28] This mineral is needed to synthesize hemoglobin for the expansion of blood volume and myoglobin for the increase in muscle mass. Because blood volume expands at a faster rate in boys than in girls, boys require more iron for tissue synthesis than girls. However, the iron loss due to menstruation makes total needs greater in young women. The RDA is set at 11 mg/day for boys (this is greater than the 8 mg RDA for adult men) and 15 mg/day for girls ages 14 to 18.[64] Girls are at a higher risk for iron deficiency because they

require more iron and they tend to eat fewer iron-rich foods, so are less likely to consume the recommended amount.

Zinc During adolescence, the increase in protein synthesis required for the growth of skeletal muscle and the development of organs increases the need for zinc. The RDA is 11 mg/day for boys and 9 mg/day for girls ages 14 to 18. A long-term deficiency results in growth retardation and altered sexual development. Although severe zinc deficiency is rare in developed countries, even mild deficiency can cause poor growth, affect appetite and taste, impair immune response, and interfere with vitamin A metabolism. Since adolescents are growing rapidly and maturing sexually, adequate zinc is essential for this age group. Good sources of zinc include meats and whole grains. The fortification of many breakfast cereals with zinc has increased the average zinc intake in the United States.[65]

Meeting Adolescents' Nutrient Needs

During adolescence, physiological changes dictate nutritional needs but peer pressure may dictate food choices. Parents often have little control over what adolescents eat, and skipped meals and meals away from home are common. A food is more likely to be selected because



Food group	Grains	Vegetables	Fruits	Dairy	Protein
Amount for an 11-yr-old male	7 ounces	3 cups	2 cups	3 cups	6 ounces
Amount for an 11-yr-old female	6 ounces	2½ cups	2 cups	3 cups	5½ ounces
Amount for an 18-yr-old male	10 ounces	4 cups	2½ cups	3 cups	7 ounces
Amount for an 18-yr-old female	8 ounces	3 cups	2 cups	3 cups	6½ ounces

choosemyplate.gov

FIGURE 15.20 MyPlate recommendations for adolescents
The recommendations shown here are for 11- and 18-year-old males and females who engage in more than 60 minutes of activity daily. The 10 oz of grains recommended for an active 18-year-old boy may seem like a huge amount. But when spread over the course of a day (in the form of, perhaps, a large bowl of cereal and toast for breakfast, two tacos for lunch, and a dinner that includes spaghetti and garlic bread), it is an amount that a teenage male can easily consume.

it tastes good, it is easy to grab on the go, or friends are eating it rather than because it is healthy.

Filling MyPlate No matter when foods are consumed during the day, an adolescent's diet should follow the recommendations of MyPlate for the appropriate age, gender, and activity level. For example, an 18-year-old boy who exercises more than an hour a day would need a diet containing about 3200 kcal/day that includes 10 oz of grains, 4 cups of vegetables, 2½ cups of fruit, 3 cups of dairy, and 7 oz of protein foods (Figure 15.20). Fruits and vegetables are the food groups most likely to be lacking in the teen diet. An analysis of fruit and vegetable consumption among teens showed that 29% of high school students consumed fruit less than once daily, and 33% consumed vegetables less than once daily.[66]

Healthy Breakfasts and Snacks The nutrients and energy provided by a healthy breakfast affect nutritional status and school performance, yet children and teens are more likely to skip breakfast than to skip any other meal.[74] Skipping breakfast may result in a span of 15 or more hours without food. Compared with non–breakfast eaters, children who eat breakfast consume more energy and nutrients.[75] Because breakfast provides energy and nutrients to the brain, children who eat breakfast are more able to concentrate and pay attention and are less disruptive at school. This, in turn, is associated with improvements in academic performance.[76]

Snacks are also an important part of the adolescent diet; they provide about a quarter of the calories for a typical teen. Unfortunately, many of these snacks are burgers, fries, sugar-sweetened beverages, potato chips, candy, cookies, and other high-fat, high-sodium, high-sugar foods. To balance these, the meals and snacks offered to adolescents at home should be high in vegetables, fruits, and low-fat dairy products. Sources of fruits and vegetables acceptable to teens include fruit juice, salads, and tomato sauce and vegetables on pizza and spaghetti.

15.5 Special Concerns of Teenagers

LEARNING OBJECTIVES

- Explain how a vegetarian diet could be high in saturated fat.
- Discuss how teens' concerns for appearance and performance can affect their nutritional status.
- Describe why peer pressure affects nutrition in teenagers.

As teens grow and become more independent, they also become more responsible for decisions about their diet and lifestyle. Choices they make regarding the foods they eat, their appearance, and their physical activities as well as the use of tobacco, alcohol, and illegal drugs can affect their nutrition as well as their overall health.

How Vegetarian Diets Affect Nutritional Health

Some children and adolescents consume vegetarian diets because their families are vegetarians, but teens may also decide to consume a vegetarian diet even if the rest of the family does not. Some do it for health reasons or to lose weight, but most give up meat because they are concerned about animals and the environment. About 3% of children and teens ages 6 to 17, or about a million school-age youth, are vegetarian.[77]

We typically think of vegetarian diets as healthful alternatives and for many teens, they are. However, as with any diet, vegetarian foods must be carefully chosen to meet nutrient needs and avoid excesses. Meatless diets can be low in iron and zinc, and vegan diets, which contain no animal products, may put teens at risk of vitamin B_{12} deficiency and inadequate calcium and vitamin D intake. If the diet includes high-fat dairy products, it can be high in saturated fat. If only refined grains are chosen and fruit and vegetable intake goals are not met, the diet can be

Bill Aron/PhotoEdit

Robyn Mackenzie/iStockphoto

FIGURE 15.21 Making healthy vegetarian choices
Cheese pizza and ice cream are vegetarian choices that are high in saturated fat and low in fiber. In contrast, whole-grain pita bread stuffed with chickpeas, corn, spinach, and tomatoes, served with low-fat milk, is low in saturated fat, high in fiber, and a good source of calcium and iron.

low in fiber (Figure 15.21). The key to a healthy vegetarian diet, like all healthy diets, is to choose a variety of nutrient-dense vegetables, fruits, grains, legumes, and dairy products (or other calcium sources).

Eating for Appearance and Performance

Appearance is probably of more concern during adolescence than at any other time of life. Many girls want to lose weight even if they are not overweight. Some boys also want to reduce their weight, but more want to gain weight to achieve a muscular, strong appearance and enhance their athletic abilities.

Eating Disorders Although eating disorders are usually not diagnosed until adolescence, the excessive concern about weight and body image that characterizes these conditions may begin as early as the preschool years. As children grow, the pressure of taking on the responsibilities of adulthood, combined with pressure from peers and society to be thin, may contribute to the development of eating disorders. It is estimated that 0.5% of adolescent females have anorexia nervosa and 1 to 2% have bulimia nervosa.[78] The nutritional consequences of an eating disorder can affect growth and development and have a lifelong impact on health (see Focus on Eating Disorders).

How Athletics Affect Nutritional Health Despite all the benefits of exercise, nutrition misinformation and the desire to excel in a sport can cause adolescent athletes to take dietary supplements, use anabolic steroids, consume inappropriate training diets, or experiment with fad diets, all of which can impact health (see Chapter 13).

Teen athletes may require more water, energy, protein, carbohydrate, and micronutrients than their less active peers, but supplements are rarely needed to meet these needs. If the extra energy needs of teen athletes are met with whole grains, fresh fruits and vegetables, reduced-fat dairy products, and lean meats, their protein, carbohydrate, and micronutrient needs will easily be met. An exception is iron, which may need to be supplemented, particularly in female athletes. The combination of poor iron intake, iron losses from menstruation and sweat, and increased needs for building new lean tissue puts many female athletes at risk for iron deficiency anemia.[79]

Many of the most dangerous practices associated with adolescent sports are those that attempt to control body weight. Some sports such as football demand that the athlete be large and muscular (Figure 15.22). In order to "bulk up," high school athletes may experiment with anabolic steroids, androstenedione (andro), and creatine. Anabolic steroids are illegal, and although they do increase muscle mass, the risks far outweigh the benefits. Androstenedione is a testosterone precursor that is also a banned substance. The use of andro and other steroid precursors has not been found to increase testosterone levels or produce any ergogenic effects, and they may cause some of the same side effects as anabolic steroids.[80] Creatine is sold as a dietary supplement. It improves exercise performance in sports requiring short bursts of activity and has not been associated with serious side effects.[81] Nonetheless, the best and safest way for young athletes to increase muscle mass is the hard way: Lift weights and eat more. Lifting weights three times a week will stimulate the muscles to enlarge and adding snacks such as milkshakes and peanut butter sandwiches will provide the energy and protein needed to support muscle growth (see Chapter 13).

Female athletes involved in sports that require lean, light bodies, such as gymnastics and ballet, are likely to abuse weight-loss diets. Sexual maturation, which causes an increase in body fat and changes in weight distribution, can be disturbing to young women involved in such sports. The combination of hard training and energy restriction can lead to a syndrome known as the female athlete triad. It includes low energy availability, menstrual dysfunction, and low

Dennis MacDonald/Age Fotostock America, Inc.

FIGURE 15.22 Bulking up
High school football players often use dietary supplements and may experiment with illegal ergogenic aids to gain muscle mass and strength.

bone mineral density, and can progress to a clinical eating disorder, amenorrhea, and osteoporosis.[82] Because energy restriction affects both male and female athletes and can impact other aspects of health and metabolism, it has been suggested that the concept of the female athlete triad be expanded to a broader syndrome called *Relative Energy Deficiency in Sport (RED-S)* (see Focus on Eating Disorders and Chapter 13).[83]

Weight loss is also a concern for adolescents participating in sports such as wrestling that require athletes to fit into a specific weight class on the day of the event. In these athletes, dangerous methods of quick weight loss—such as severe energy intake restriction, water deprivation, self-induced vomiting, and diuretic and laxative abuse—are common practice. Low-energy diets can interfere with normal growth and may be too limited in variety to meet these athletes' needs for vitamins and minerals. Even more of a danger is the practice of restricting water intake and encouraging sweat loss to decrease body weight. This may achieve the temporary weight loss necessary to put the athlete in a lower weight class, but dehydration is dangerous and can impair athletic performance (see Chapters 10 and 13).

Oral Contraceptive Use

Oral contraceptive hormones may be prescribed to adolescent girls for a number of reasons and can change nutritional status because they affect nutrient metabolism. Oral contraceptives may cause a rise in fasting blood sugar and a tendency toward abnormal glucose tolerance in those with a family history of diabetes. They may also cause changes in body composition, including weight gain due to water retention and an increase in lean body mass. Oral contraceptives may reduce the need for iron by reducing menstrual flow and increasing iron absorption. Therefore, a special RDA for iron of 11.4 mg/day has been established for those taking oral contraceptives.[64]

Teenage Pregnancy

Because adolescent girls continue to grow and mature for several years after menstruation starts, the diet of a pregnant teenager must meet her own nutrient needs for growth and development as well as the needs of pregnancy. These elevated needs put the pregnant adolescent at nutritional risk. In order for the mother and fetus to remain healthy, special attention must be paid to all aspects of prenatal care, including nutrient intake (see Chapter 14). Due to the special

nutrient needs of this group, the DRIs have included a life-stage group for pregnant girls age 18 or younger.

Tobacco Use

Approximately 18% of high school students in the United States smoke cigarettes.[84] Smoking affects hunger, body weight, and nutritional status, and increases the risk of cardiovascular disease and lung cancer. Many teens start smoking in order to promote weight loss or maintenance. Because smoking is associated with lower body weights in adult women, some teens believe smoking will curb their appetite and help them stay thin or lose weight.[85] Smokers often do not want to quit because they fear that they will gain weight. Smoking impacts nutrient intake. A comparison of the diets of smokers and nonsmokers found that smokers consumed fewer fruits and vegetables, leading to lower intakes of folate, vitamin C, and fiber.[86] This dietary pattern can affect nutritional status and the risk of developing chronic disease. In addition to being associated with lower intakes of vitamin C, the increase in oxidative stress caused by smoking increases the requirement for vitamin C; thus the DRIs recommend that smokers consume an extra 35 mg/day.[87]

Alcohol Use

Although it is illegal to sell alcohol to adolescents, alcoholic beverages are commonly available at teen social gatherings, and the peer pressure to consume them is strong. Surveys of American youth suggest that almost 39% of students in 9th through 12th grades have had at least one drink during the previous month; of these, 22% have engaged in **binge drinking**.[88] Binge drinking is a problem on college campuses that causes about 50 deaths and hundreds of cases of alcohol poisoning annually. It is estimated that about 40% of college students "binge" on alcohol at least once during a two-week period.[89] Alcohol is a drug that has short-term effects that occur soon after ingestion and long-term health consequences that are associated with overuse. It provides 7 kcal/g but no nutrients. The alcohol in the diet displaces foods that are nutritious. Once ingested, alcohol alters nutrient absorption and metabolism. The metabolism of alcohol as well as its impact on nutritional and overall health are discussed in Focus on Alcohol.

binge drinking A pattern of drinking that brings a person's blood alcohol concentration to 80 mg/100 mL or above.

OUTCOME

After a few months of consuming healthy, low-calorie meals and exercising regularly, Felicia had lost 2 lb. More important, she began to feel better about herself and was even more motivated to change her old habits to improve her health and appearance. Her fitness improved enough for her to ride her bike to school. She began helping her mother find healthy recipes and learned to make lower-calorie choices when she ate out or snacked with friends. For example, instead of ice cream, she chose sorbet or low-fat frozen yogurt, and she passed on burgers and fries in favor of a grilled chicken sandwich and a salad. When she was hungry, she reached for fruit or raw vegetables. Felicia began taking a multivitamin and mineral supplement to make sure she got enough iron, and she drank fat-free milk with her meals for a low-calorie source of calcium. She still ate lunch in the school cafeteria, but learned to make better choices from the foods offered.

Felicia, now 15 years old, has grown 3 in. and gained only 5 lb during the past two years. Her BMI is at about the 90th percentile. Her self-confidence has increased so much that she is considering trying out for the field hockey team next year. **If she grows another 2 in. and gains weight slowly, by the time she is 17 she will have a BMI in the healthy range.**

SUMMARY

15.1 Starting Right for a Healthy Life

- The current diet of American children is low in fruits, vegetables, whole grains, dairy, and seafood and high in processed foods that are high in solid fat, salt, and added sugar.
- The poor diet and low activity level of children contribute to obesity, diabetes, elevated blood pressure, and unhealthy blood lipid levels.
- Healthy eating habits learned in childhood set the stage for nutrition and health in the adult years.

15.2 Nourishing Infants, Toddlers, and Children

- Growth that follows standard patterns is the best indicator of adequate nutrition. BMI-for-age growth charts can be used to evaluate whether a child is normal weight, underweight, overweight, or obese.
- Energy and protein needs per kilogram of body weight decrease as children grow, but total needs increase because of the increase in total body weight and activity level. Children need a greater percentage of dietary fat and the same percentage of carbohydrates as adults. Dietary carbohydrates should come primarily from whole grains, vegetables, fruits, and milk. Baked goods, candy, and soda should be limited.
- Under most situations, water needs in children can be met by consuming enough fluid to alleviate thirst. Activity and a hot environment increase water needs. As with adults, the typical sodium intake in children and teens currently exceeds the recommended amounts.
- Calcium, vitamin D, and iron intakes are often low in children's diets. Adequate calcium and vitamin D are important for preventing osteoporosis later in life, but intakes are declining due to reductions in the consumption of dairy products. Excessive milk consumption can contribute to iron deficiency.
- Introducing solid foods between 4 and 6 months of age adds iron and other nutrients to the diet and aids in muscle development. Newly introduced foods should be appropriate to the child's stage of development and offered one at a time to monitor for food allergies.
- In order for children to meet nutrient needs and develop nutritious habits, a variety of healthy foods should be offered at meals and snacks throughout the day. The National School Lunch Program provides low-cost school lunches designed to meet nutrient needs and promote healthy diets. Some children can benefit from vitamin/mineral supplements, but children who consume a well-selected, varied diet can meet all their vitamin and mineral requirements with food.

15.3 Nutrition and Health Concerns in Infants and Children

- In sensitive individuals food allergies are triggered by the absorption of food allergens, most of which are proteins. Food allergies involve antibody production by the immune system and are more common in infancy because the infant's immature gastrointestinal tract is more likely to absorb incompletely digested proteins. Specific foods that cause allergies can be identified by an elimination diet and food challenge. Unlike food allergies, food intolerances do not involve the immune system.
- Dietary patterns high in sugars combined with poor dental hygiene put children at risk of dental caries. Sugar intake has been accused of worsening attention deficit/hyperactivity disorder symptoms, but there is little evidence that that is the case. Lack of sleep, overstimulation, the desire for more attention, lack of physical activity, and caffeine consumption may contribute to hyperactivity.
- Children's health is harmed by lead. Lead disrupts the activity of neurotransmitters and thus interferes with the functioning of the nervous system. Due to reductions in the use of lead, the number of children with high blood lead levels has declined dramatically.
- Obesity is a growing problem among children. Watching television contributes to childhood obesity by promoting snacking on high-calorie foods and by reducing the amount of exercise children get. Fast food meals contribute to obesity because they are high in calories; in addition they are typically low in fruits, vegetables, and dairy. Solutions to the problem of childhood obesity involve action from government, the food industry, health-care providers, communities, schools, and parents and families. Individuals who are overweight need to change behaviors to decrease food intake and increase activity.

15.4 Adolescents

- During adolescence, body composition changes and the nutritional requirements of boys and girls diverge. Males gain more lean body tissue, while females have a proportionally greater increase in body fat.
- During adolescence, accelerated growth and sexual maturation have an impact on nutrient requirements. Total energy and protein requirements are higher than at any other time of life. Vitamin requirements increase to meet the needs of rapid growth. Vitamin D, calcium, iron, and zinc are likely to be low in the adolescent diet. Intake of vitamin D and calcium is often low because teens drink soda instead of milk. Iron deficiency anemia is common, especially in girls as they begin losing iron through menstruation.
- Adolescent nutrient needs can be met by following the recommendations of MyPlate. Since meals are frequently missed, healthy snacks should be included in the diet.

15.5 Special Concerns of Teenagers

- Teens often turn to vegetarian diets, sometimes for environmental reasons and sometimes for weight control. Poorly planned vegetarian diets can put teens at risk of iron, zinc, calcium, vitamin D, or vitamin B_{12} deficiency. Poor food choices can result in vegetarian diets that are high in saturated fat and low in fiber.
- Psychosocial changes occurring during the adolescent years make physical appearance of great concern. Eating disorders are more common in adolescence than at any other time. Adolescent athletes are susceptible to nutrition misinformation, and they may experiment with dangerous practices such as using anabolic steroids to increase muscle mass or fad diets and fluid restriction to lose weight.
- During the teen years, pregnancy, the use of oral contraceptives, and tobacco may affect nutritional status. Alcohol consumption and overconsumption often start in the teen years and can have negative nutritional and social consequences.

CHAPTER OUTLINE

16.1 What Is Aging?
- How Long Can Americans Expect to Live?
- How Long Can Americans Expect to Be Healthy?

16.2 What Causes Aging?
- Programmed Cell Death
- Wear and Tear
- How Genetics, Environment, and Lifestyle Interact

16.3 Aging and the Risk of Malnutrition
- How Physiological Changes Affect the Risk of Malnutrition
- Why Medical Conditions Contribute to Malnutrition
- How Economic, Social, and Psychological Factors Affect Nutritional Status

16.4 Nutritional Needs and Concerns of Older Adults
- Energy and Macronutrient Needs
- Micronutrient Needs

16.5 Keeping Older Adults Healthy
- Maintaining a Healthy Weight
- How to Plan a Healthy Diet for Older Adults
- Physical Activity for Older Adults
- How to Prevent Food Insecurity
- Nutrition Programs for the Elderly

(©iStockphoto)

Robert E Daemmrich/Stone/Getty Images, Inc.

Nutrition and Aging: The Adult Years

16

CASE STUDY

Hiroshi Yagi/Getty Images, Inc.

Cheng is 70 years old and has always been healthy. He and his wife exercise regularly, watch their weight, and eat a healthy diet. Recently, Cheng experienced a few episodes of forgetfulness, but he laughed it off as old age. Then he began feeling tired and having tingling in his hands and feet, difficulty walking, and diarrhea. Fearing the worst, he made an appointment to see his doctor.

Laboratory tests showed that Cheng had low levels of vitamin B_{12}. A diet history revealed that his diet didn't provide much of the vitamin. He eats lots of grains, fruits, and vegetables, which do not provide vitamin B_{12}, and very little meat or dairy, which are sources of this vitamin. The doctor explained that Cheng's symptoms were due to a vitamin B_{12} deficiency. The deficiency was probably caused by a condition common in older adults that reduces the ability to absorb vitamin B_{12} from food. Cheng's doctor gave him an injection of vitamin B_{12} and recommended that he start taking a daily supplement containing the vitamin.

Because of our plentiful food supply and the availability of vitamin supplements, Americans tend to think of vitamin deficiencies as a thing of the past, or perhaps as conditions that afflict people only in the developing world. For the most part that is true. **But, as Cheng's case illustrates, older adults are a segment of the U.S. population that is at risk of malnutrition due to physical, psychological, and social changes that may limit intakes, or medical conditions or medications that interfere with nutrient absorption or utilization.**

Tony Freeman/PhotoEdit

FIGURE 16.1 Aging
The five generations of women in this family illustrate that the process of aging occurs continuously in individuals of all ages.

16.1 What Is Aging?

LEARNING OBJECTIVES

- Define aging.
- Compare life expectancy with healthy life expectancy.
- Explain what is meant by *compression of morbidity*.

Biologically, **aging** is not something that begins at age 55, 65, or 75; it is a process that begins with conception and continues throughout life (Figure 16.1). Aging involves the inevitable accumulation of changes with time that are associated with and responsible for an ever-increasing susceptibility to disease and death. The maximum age to which any human can live—the **life span**—is about 100 to 120 years. Life span is a characteristic of a species; dogs can live about 20 years, gorillas 39 years, and mice only about 3 years. Life span is believed to

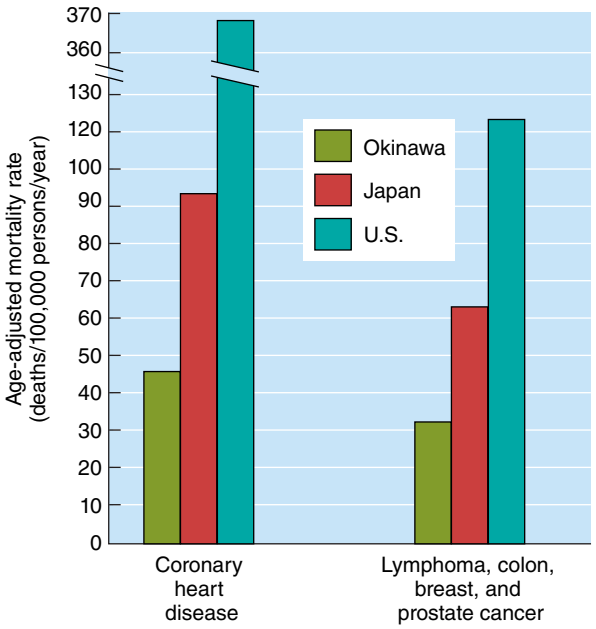
SCIENCE APPLIED

Eat Less—Live Longer?

Throughout history, humans have searched for ways to stay young, avoid the ravages of old age, and extend life. Ponce de Leon came up empty in his search for the fountain of youth, but an Italian nobleman named Luigi Cornaro may have come closer. Born in 1464, Cornaro lived a life of excess until the age of 35, when a physician advised him to adopt a more frugal existence. His response was to "eat as little as possible," which he promoted in a series of books translated as "The Art of Living Long."[2] He lived to 102 at a time when average life expectancy was only about 30. Had he found the fountain of youth?

THE SCIENCE

Since the 1930s, research studies have described the life-extending effect of caloric restriction in rats and other organisms.[3,4] Consuming a calorie-restricted diet (one that provides 20 to 40% less than the recommended intake) that meets the need for all essential nutrients has been shown to extend the maximal life span of rodents by as much as 60%.[5] It also reduces age-related chronic disease, improves immune function, increases resistance to numerous stressors and toxins, and maintains function later into life.



In the United States mortality from heart disease is about eight times higher, and certain forms of cancer are about four times higher, than in Okinawa.

To explore the possibility that caloric restriction would lengthen life and reduce chronic disease in an animal more closely related to humans, two studies, one at the National Institute on Aging and one at the University of Wisconsin, were begun in the 1980s.[6] In both studies, adult rhesus monkeys were fed nutritionally adequate diets containing 30% fewer calories than a control group. In both studies, beneficial health effects were reported in the calorie-restricted animals; however, only the University of Wisconsin study

be genetically determined. The only experimental treatment that has been found to extend the life span of mammals is a nutritional manipulation called *caloric restriction*.[1] Restricting the energy intake of animals to about 70% of typical intake slows and/or delays the aging processes. Although the underlying biological mechanisms responsible for the life span–extending effects of this diet are still under investigation, changes in four regulatory pathways are believed to play an important role.[2] Despite promising data from animal studies, caloric restriction is not currently considered a viable option for extending life in humans (see **Science Applied: Eat Less—Live Longer?**).

aging The process of becoming older. It is genetically determined and modulated by environmental and lifestyle factors.

life span The maximum age to which members of a species can live.

How Long Can Americans Expect to Live?

Although humans can live to be 120 years old, most do not. **Life expectancy**, the average length of time that a person can be expected to live, varies between and within populations. It is affected by genetics, lifestyle, and environmental factors. In the United States in 1900, life

life expectancy The average length of life for a population of individuals.

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

reported that the calorie-restricted group lived longer than controls.[7,8]

Epidemiologic evidence of the benefits of calorie restriction in humans comes from studies of the people of Okinawa, the longest-lived people on Earth.[9] Until recently, Okinawans practiced calorie restriction by eating until they were only 80% full. In addition, they led active lives, worked as farmers, and consumed a nutrient-dense diet that was high in green and yellow vegetables, whole grains, soy, fish, and lean meat and low in refined grains, saturated fat, salt, and sugar.[10] Older Okinawans maintain a low BMI and have a lower incidence of chronic diseases than people living in the United States or on mainland Japan (see graph).[9] Studies have also been conducted in members of the Caloric Restriction Society, a group that practices self-imposed caloric restriction. Those who voluntarily consumed 30% fewer calories than a typical Western diet for 6.5 years had lower BMIs; lower total cholesterol, LDL cholesterol, and triglycerides; higher HDL cholesterol; and lower fasting glucose, fasting insulin, blood pressure, and inflammatory markers.[5] To study human caloric restriction in a more controlled setting, the National Institute on Aging has sponsored a randomized controlled trial to investigate the effects of 2 years of a 25% calorie restriction in normal-weight individuals on disease risk and the aging process. The 2-year data are not yet available, but preliminary studies in overweight individuals found caloric restriction for 6 to 12 months caused a reduction in body weight, increased insulin sensitivity, and improved indices of oxidative stress.[2]

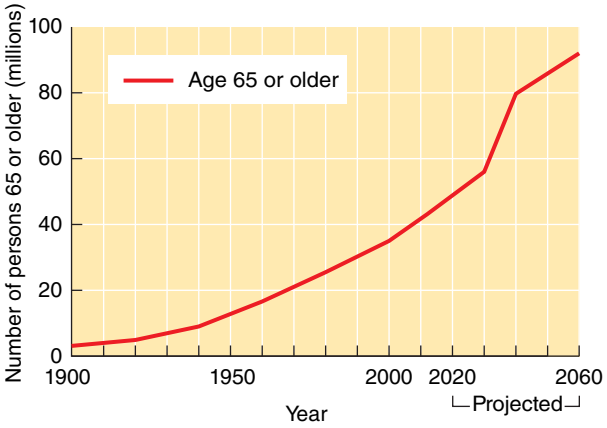
THE APPLICATION

Studies in monkeys and humans indicate that caloric restriction without malnutrition protects against obesity, type 2 diabetes, and cardiovascular disease and decreases risk factors for cancer.[5] Despite these benefits, following a calorie-restricted diet is not easy. Caloric restriction would mean that a person who typically eats about 2000 kcal/day could eat only 1200 to 1600 kcal/day. This would cause food cravings, weight loss, a lack of energy, and in some cases psychological consequences. To eat this little while meeting nutrient needs requires carefully planned meals and snacks; a poorly planned diet will lead to malnutrition.

The ideal situation would be to gain the benefits of caloric restriction without having to cut calories so severely. Data in both human and other species suggest that the balance of nutrients such as protein, amino acids, fat, minerals, and phytochemicals as well as calorie restriction may be important in regulating both life span and healthy life span. Dietary modifications such as protein restriction, methionine restriction, and alternate-day fasting have shown effects similar to that observed with overall calorie restriction.[11] Drugs that mimic the effects of caloric restriction are also being investigated. A number of promising candidates have been developed, but thus far none have shown consistent benefits in clinical trials.[12]

THINK CRITICALLY: If a promising anti-aging drug is developed in animals, what problems might arise in trying to test it in humans?

FIGURE 16.2 Our aging population



A. Projections indicate that by 2060 there will be over 90 million people in the United States who are age 65 or older.[14]

Purestock/Getty Images, Inc.

B. Chronological age is not always the best indicator of a person's health. A person who is 75 may have the vigor and health of someone who is 55, or vice versa. Some older adults are healthy, independent, and active, whereas others are chronically ill, dependent, and at high risk for malnutrition.

THINK CRITICALLY

How will the increase in the elderly population affect health-care costs?

expectancy was 50 years, but today, with advances in technology and improved nutrition and health care, the average is about 78.8 years.[13] With this increase in life expectancy has come an increase in the number of older adults. The population of older adults, those 65 years of age and older, grew from 3 million in 1900 to 43.1 million in 2012, or about 13.7% of the population (Figure 16.2A). Over the same time period, the oldest-old population, those over the age of 85 years, grew from just over 100,000 to 5.9 million. This increase in the number of older adults is expected to continue. By 2040, the population of Americans ages 65 and older is projected to increase to 79.7 million.[14]

compression of morbidity The postponement of the onset of chronic disease so that disability occupies a smaller and smaller proportion of the life span.

How Long Can Americans Expect to Be Healthy?

Even though average life expectancy in the United States has increased to over 76.4 years for men and 81.2 years for women,[13] the average healthy or active life expectancy is only 65.1 years for men and 68 years for women.[15] This means that, on average, men spend the last 11 years of life and women the last 13 years physically or socially restricted by disease and disability. The goal of successful aging is to increase not only life expectancy but the number of years of healthy, active life that an individual can expect (Figure 16.2B). This is achieved by slowing the physiological changes that accumulate over time and postponing the diseases of aging long enough to approach or reach the limits of life span before any adverse symptoms appear. This is referred to as **compression of morbidity**. When applied to the population as a whole, this term means that people are healthier and living longer (Figure 16.3); applied to the individual, it means staying healthy through the later years of life.

Because the incidence of disease and disability increases with increasing age, the older population accounts for a large part of the public health budget. Thus, keeping older adults healthy is beneficial not only for the aging individuals themselves, but for the health-care system as well. Postponing the changes that occur with age is an important public health goal.

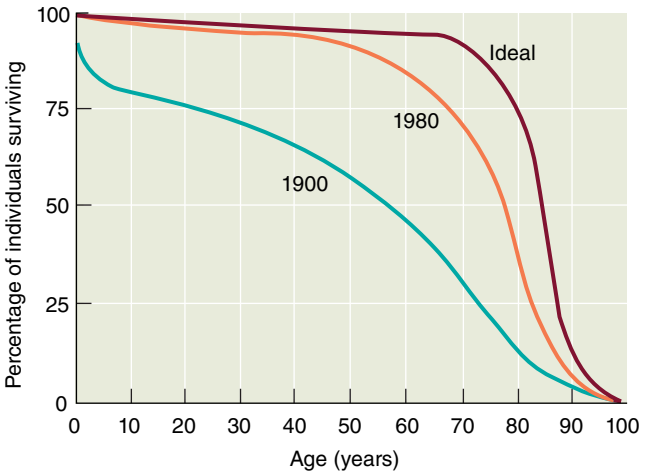


FIGURE 16.3 Compression of morbidity[16]
The decline in deaths from infectious diseases between 1900 and 1980 allowed more people to survive into adulthood. Delaying the onset of chronic diseases will allow more people to remain healthy and survive into their seventies, eighties, and nineties. This is illustrated by the curve labeled "Ideal."

16.2 What Causes Aging?

LEARNING OBJECTIVES

- Describe the biological causes of aging.
- Discuss genetic, environmental, and lifestyle factors that affect the aging process.

Although universal to all living things, aging is a process we don't fully understand. We do know that as organisms become older, the number of cells they contain decreases and the functioning of the remaining cells declines. As tissues and organs lose cells, the ability of the organism to perform the physiological functions necessary to maintain homeostasis decreases; disease becomes increasingly common and the risk of malnutrition increases. This loss of cells and cell function occurs throughout life, but the effects are not felt for many years because organisms begin life with extra functional capacity, or **reserve capacity**. Reserve capacity allows an organism to continue functioning normally despite a decrease in the number and function of cells. In young adults, the reserve capacity of organs is 4 to 10 times that required to sustain life. As a person ages and reserve capacity decreases, the effects of aging become evident in all body systems.

reserve capacity The amount of functional capacity that an organ has above and beyond what is needed to sustain life.

Two major hypotheses have been advanced to explain why aging occurs. One favors the idea of a genetic clock and argues that genetically programmed cell death leads to aging. The other views the events of aging as the result of cellular wear and tear. The actual cause of the cell death associated with aging is probably some combination of both of these, and the rate at which cell death occurs and at which aging proceeds is determined by the interplay among our genetic makeup, our lifestyle, and the environment in which we spend our years.

Programmed Cell Death

Programmed cell death refers to the selective, orderly death of individual cells or groups of cells that is triggered when genes that disrupt cell function are activated. It allows changes in body structure and shape to occur during growth and development and helps maintain homeostasis at any age by getting rid of old or damaged cells. Both too much and too little programmed cell death are hypothesized to contribute to aging.[17] For example, too much cell death decreases the total number of cells, resulting in a loss of organ function and a decrease in life span. Too little cell death will allow damaged cells such as cancer cells to proliferate.

programmed cell death The death of cells at specific predictable times.

Wear and Tear

The accumulation of cellular damage, referred to as *wear and tear*, is also hypothesized to contribute to aging. Wear and tear may result from errors in DNA synthesis, increases in glucose levels, or damage caused by free radicals. Free radicals are reactive chemical substances that are generated from both normal metabolic processes and exposure to environmental factors (see Chapter 8 and online Focus on Metabolism). They cause oxidative damage to proteins, lipids, carbohydrates, and DNA, and may also indirectly harm cells by producing toxic products. For example, age spots—brown spots that appear on the skin with age—are caused by the oxidation of lipids, which produces a pigment called *lipofuscin*, or age pigment. The damage done to cells by free radicals is associated with aging and has been implicated in the development of a number of chronic diseases common among older adults, including cardiovascular disease and cancer.

How Genetics, Environment, and Lifestyle Interact

The rate at which the changes associated with aging accumulate depends on the genes people inherit, the environment they live in, and their lifestyle. Genes determine the efficiency with which cells are maintained and repaired. Individuals with less cellular repair capacity will lose cells more readily, and consequently age more quickly. Likewise, genes determine susceptibility

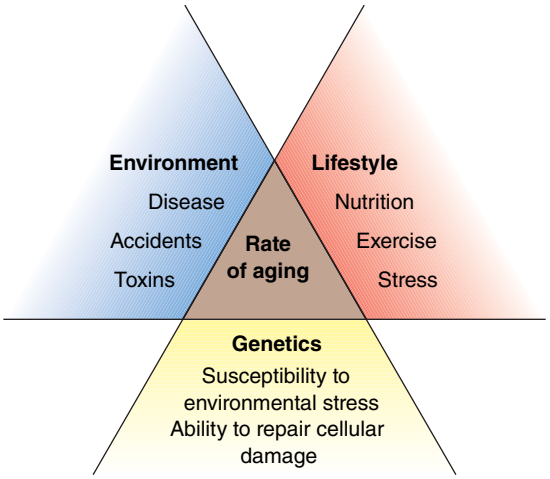


FIGURE 16.4 Factors that affect the rate of aging
The rate at which individuals age is affected by their genetic makeup, the environment in which they live, and the lifestyle choices they make.

THINK CRITICALLY

Based on the information in this figure, what could someone do to slow his or her rate of aging?

to age-related diseases such as cardiovascular disease and cancer. However, individuals who inherit a low capacity to repair cellular damage may still live long lives if they reside in an environment with few factors that damage cells and if they eat well and exercise regularly. In contrast, individuals with exceptional cellular repair ability may accumulate cellular damage rapidly and die young if they smoke cigarettes, consume a diet high in saturated fat and low in antioxidant nutrients, and live sedentary lives. No matter what individuals' genes predict about how long they will live, their actual **longevity** will also be affected by lifestyle factors and the extent to which they are able to avoid accidents and disease (Figure 16.4).

longevity The duration of an individual's life.

16.3 Aging and the Risk of Malnutrition

LEARNING OBJECTIVES

- Discuss how the physiological changes of aging can affect nutritional status.
- Explain how changes in body composition affect energy needs.
- Explain how the nutrient needs of older adults are affected by disease and medication use.
- Discuss economic, social, and psychological factors that increase the risk of malnutrition.

The aging process usually does not cause malnutrition in healthy, active adults, but nutritional health can be compromised by the physiological changes that occur with age, the presence of disease, and economic, social, and psychological circumstances (Table 16.1). These

TABLE 16.1 Factors That Increase the Risk of Malnutrition among the Elderly

• **Reduced food intake due to:**
Decreased appetite caused by lack of exercise, depression, or social isolation
Changes in taste, smell, and vision
Dental problems
Limitations in mobility
Medications that restrict mealtimes or affect appetite
Lack of money to buy food
Lack of nutrition knowledge
• **Reduced nutrient absorption and utilization due to:**
Gastrointestinal changes
Medications that affect absorption
Diseases such as diabetes, kidney disease, alcoholism, and gastrointestinal disease
• **Increased nutrient requirements due to:**
Illness with fever or infection
Injury or surgery
• **Increased nutrient losses due to:**
Medications that increase excretion of nutrients
Diseases such as gastrointestinal and kidney disease

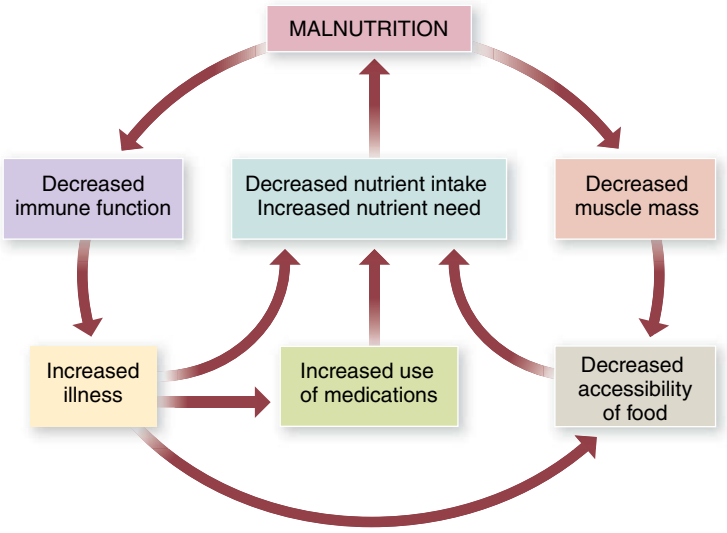


FIGURE 16.5 Causes and consequences of malnutrition
Many of the physiological changes and health problems associated with aging can affect nutritional status. This illustration shows that decreases in muscle mass and immune function and an increase in medication use contribute to malnutrition and that, in turn, malnutrition reduces immunity and muscle mass.

factors can increase the risk of malnutrition by altering nutrient needs and decreasing the motivation to eat and the ability to acquire and enjoy food. Malnutrition then exacerbates some of these factors, contributing to a downward health spiral from which it is difficult to recover (Figure 16.5).

How Physiological Changes Affect the Risk of Malnutrition

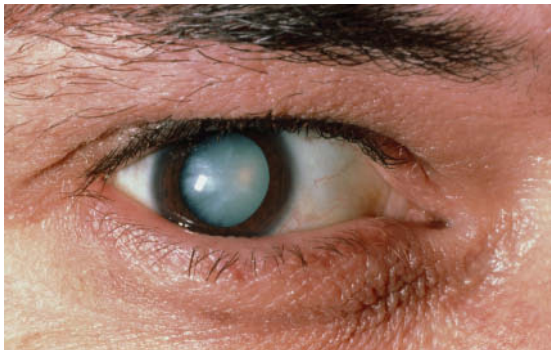
It is difficult to determine which of the changes that occur with aging are inevitable consequences of the aging process and which are the result of disease states. But whether caused by disease or normal aging, the changes that occur in organs and organ systems can affect nutritional status by altering the appeal of food, the ability to obtain food, and the digestion, absorption, metabolism, and excretion of nutrients.

macular degeneration Degeneration of a portion of the retina that results in a loss of visual detail and blindness.

cataract A disease of the eye that results in cloudy spots on the lens (and sometimes the cornea) that obscure vision.

Sensory Decline Beginning around age 60, there is a progressive decline in the ability to taste and smell; this becomes more severe in persons over 70. The deterioration of these senses can contribute to impaired nutritional status by decreasing the appeal and enjoyment of food.[18] Some studies suggest that the decrease in taste acuity is due to a reduction in the number of taste buds on the tongue; others suggest that it is the result of changes in sensitivity to specific flavors such as salty and sweet. The appeal of food is also affected by the decline in the sense of smell. Odors provide important clues to food acceptability before food enters the mouth and, once in the mouth, some molecules reach the nasal cavity where their odor is detected. It is the blending of the odor message from the nasal cavity and the taste message from the tongue that provides the overall food flavor. When the sense of smell is diminished, food is not as flavorful.

Vision also typically declines with age, making shopping for and preparation of food difficult. **Macular degeneration** is the most common cause of blindness in older Americans. The macula is a small area of the retina of the eye that distinguishes fine detail. With age, oxidative damage reduces the number of viable cells in the macula. As the macula degenerates, visual acuity declines, ultimately resulting in blindness. **Cataracts** are another common reason for declining sight (Figure 16.6). Of people who live to age 85, half will have cataracts that impair vision. Oxidative damage is believed to cause both macular degeneration and cataracts. Therefore, a diet high in foods containing antioxidant nutrients might slow or prevent these eye disorders.[19]



Sue Ford/Photo Researchers, Inc.

FIGURE 16.6 Cataracts
Cataracts cause the lens of the eye to become cloudy and impair vision. When cataracts obscure vision, the affected lens can be removed and replaced with an artificial plastic lens.

Alterations in Gastrointestinal Function Aging causes changes in the gastrointestinal tract and its accessory organs that may alter the palatability as well as the digestion of food and the absorption of nutrients. One change is a decrease in the secretion of saliva. Saliva provides lubrication for easy swallowing and mixes with food to allow it to be tasted. A reduction in saliva makes swallowing difficult and decreases the taste of food. Saliva is also an important defense against tooth decay because it helps wash material away from the teeth and contains substances that kill bacteria. Thus, a dry mouth increases the likelihood of tooth decay and **periodontal disease**. Loss of teeth and improperly fitting dentures limit food choices and can contribute to poor nutrition in the elderly.

periodontal disease A degeneration of the area surrounding the teeth, specifically the gum and supporting bone.

Changes in stomach emptying and stomach secretions can also affect nutritional status. In older adults, the rate of stomach emptying may be slower, which can reduce hunger and, therefore, nutrient intake. Reductions in gastric secretions can affect the absorption of some nutrients. It is estimated that 10 to 30% of American adults over age 50 and 40% of those in their 80s have **atrophic gastritis** (see Chapter 3). This inflammation of the stomach lining is accompanied by a decrease in the secretion of stomach acid and, in severe cases, a reduction in the production of intrinsic factor (see Chapter 8).[20] When stomach acid is reduced, the enzymes that release vitamin B_{12} from food do not function properly and the vitamin B_{12} naturally present in food cannot be absorbed. Absorption of iron, folate, calcium, and vitamin K may also be reduced. Reduced stomach acid secretion also allows microbial overgrowth in the stomach and small intestine.[20] The increase in the number of gut microbes that use vitamin B_{12} further reduces the amount of the vitamin available for absorption into the body.

atrophic gastritis An inflammation of the stomach lining that causes a reduction in stomach acid and allows bacterial overgrowth.

With age, there is a reduction in digestive enzymes from the pancreas and small intestine, but there is enough reserve capacity that digestion and absorption are rarely significantly impaired. The colon undergoes functional changes, including decreased motility and elasticity, weakened abdominal and pelvic muscles, and decreased sensory perception, which can lead to constipation. Low fiber and fluid intakes and lack of activity also contribute to constipation. About 33% of adults over age 60 experience the symptoms of constipation, compared to only 16% of adults overall.[21] Maintaining regular exercise and consuming adequate fluid and fiber are safe ways to prevent constipation.

Changes in Other Organs Age-related changes in organs other than those of the gastrointestinal tract may also affect nutrient metabolism. Most absorbed nutrients travel from the intestine to the liver for metabolism or storage. The liver has a greater regenerative capacity than most organs, but with age, liver size and blood flow decrease and fat accumulates; these changes eventually decrease the liver's ability to metabolize nutrients and break down drugs and alcohol. With age, the pancreas may become less responsive to blood glucose levels, and the body cells may become more resistant to insulin, resulting in diabetes. Changes in the heart and blood vessels reduce blood flow to the kidneys, making waste removal less efficient. The kidneys themselves become smaller and their ability to filter blood and to excrete the products of protein breakdown declines. In some individuals, blood urea levels may increase if protein intake is too high. The ability of the kidneys to concentrate urine also decreases with age, as does the sensation of thirst, increasing the risk of dehydration.

Changes in Body Composition As people age, body composition changes. Muscle and bone mass decrease and body fat increases, especially in the abdomen. The decrease in muscle size and strength is referred to as **sarcopenia** (Figure 16.7).[22] Sarcopenia affects primarily the skeletal muscles needed to move the body, reducing strength and endurance. The loss of muscle strength contributes to **physical frailty**, which is characterized by general weakness, decreased endurance, impaired mobility, and poor balance; this increases the risk of falls and fractures. The decrease in bone mass that occurs with aging often results in osteoporosis, which further increases the risk of fractures.

sarcopenia Progressive decrease in skeletal muscle mass and strength that occurs with age.

physical frailty Impairment in function and reduction in physiological reserves severe enough to cause limitations in the basic activities of daily living.

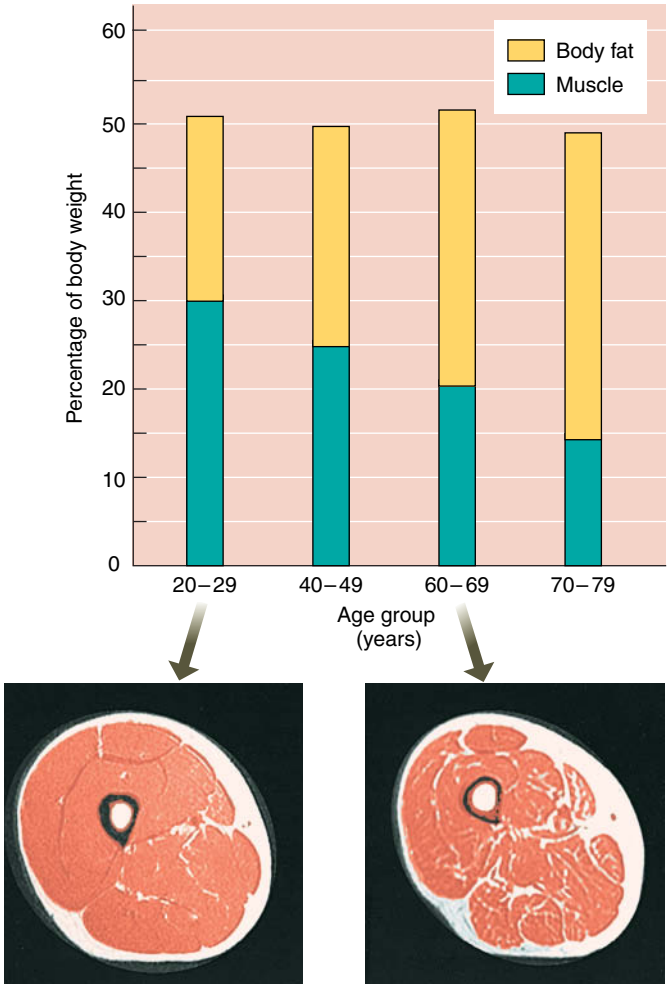
As muscle and bone mass decrease in older adults, body fat stays the same or increases, increasing the percentage of body fat and the risk of obesity. The incidence of obesity in older age groups, as in younger adults, has increased during the past 50 years. Over 70% of adults age 60 or older are overweight or obese and about 35% are obese.[23] The risk of death associated with obesity is lower in older than in younger adults, but obesity still increases the risk of health

ANALYZE THE DATA

By what percentage does muscle mass decrease between age 20 and age 70?

FIGURE 16.7 Changes in the proportion of muscle and fat with age

A. With age, the proportion of muscle mass decreases and that of body fat increases.[26]



© Courtesy S. A. Jubias and K. E. Conley, University of Washington Medical Center

B. These magnetic resonance images of a thigh cross section from a 25-year-old man (left) and a 65-year-old man (right) show that, although the thighs are of similar size, the thigh of the older man has more fat (shown in white) around and through the muscle, indicating significant muscle loss.

complications that reduce the quality of life.[24] It contributes to a higher risk of type 2 diabetes, cardiovascular disease, metabolic syndrome, certain cancers, hypertension, stroke, sleep apnea, and arthritis. Although obesity makes many chronic conditions worse, the loss of bone and the risk of osteoporosis are reduced in individuals who weigh more.[25] This is partly due to the added mechanical stress on the bones caused by carrying excess body weight and partly due to the release of estrogen by body fat (see Chapter 11).

Sarcopenia makes the tasks of day-to-day life, including acquiring and preparing food, more difficult, increasing the risk of malnutrition. In the oldest-old (those 85 years of age and older), it is often the determining factor in whether an individual can continue to live independently. Obesity also contributes to suboptimal physical functioning. In many older adults sarcopenia and obesity coexist. This combination is associated with higher morbidity and mortality and a greater loss of functional strength than either condition alone.[24]

Changes in Hormone Levels Some of the hormonal changes that occur with age are considered part of the normal aging process. Others may be a symptom of a disease process. For example, a decrease in thyroid hormone levels often occurs with aging. In many individuals the decrease is minimal and causes no symptoms. Whether treatment is necessary and beneficial depends on the thyroid hormone levels and the presence of clinical symptoms.[27]

Estrogen The most striking and rapidly occurring age-related hormonal change is **menopause**. Menopause normally occurs in women between the ages of 45 and 55. During menopause, the cyclical release of the female hormones estrogen and progesterone slows and eventually stops, causing ovulation and menstruation to cease. The period of decline in estrogen levels is accompanied by changes in mood, skin, and body composition (an increase in body fat and a decrease in lean tissue). The reduction in estrogen decreases the risk of breast cancer but increases the risk of heart disease to a level more similar to that in men. Reduced estrogen levels also increase the risk of osteoporosis by increasing the rate of bone breakdown and decreasing calcium absorption from the intestine (see Chapter 11). Estrogen used to be prescribed liberally to older women to alleviate the symptoms of menopause and reduce the risk of osteoporosis and heart disease. This hormone replacement therapy is no longer as common because studies have found that, although it does reduce menopausal symptoms and the risk of bone fractures, it increases the risk of heart disease, blood clots, stroke, breast cancer, and problems with memory and thinking.[28]

menopause Physiological changes that mark the end of a woman's capacity to bear children.

Menopause does not occur in men, but with age men do experience a gradual decrease in testosterone levels, which may contribute to a decrease in muscle mass and strength.

Growth Hormone Growth hormone stimulates growth and protein synthesis. Levels gradually decline with age in both men and women and may be responsible for some of the decrease in lean body mass, increase in fat mass, bone loss, and decrease in vitality and physical function that occur with age. Despite the promise of growth hormone as an anti-aging therapy, there is little evidence that it extends life or improves health.[29] A few studies have found growth hormone treatment to slightly increase lean body mass and decrease fat mass in older men, but there is little evidence that it improves strength, physical performance, or quality of life. In addition, growth hormone administration has side effects including edema, joint pain, carpal tunnel syndrome, and insulin resistance.[29]

DHEA DHEA (dehydroepiandrosterone) is a precursor to the sex hormones testosterone, estrogen, and progesterone. DHEA levels in older adults are as low as 10 to 20% of those found in young adults. DHEA supplements sold over the counter claim to strengthen bones, muscles, and the immune system, and to prevent diabetes, obesity, heart disease, and cancer. Although there are reports of positive effects of DHEA on muscle mass and strength, bone density, cardiovascular disease, mood, and sexual function few of these studies are large enough or long enough to conclude that DHEA is beneficial for aging or age-related diseases and the long-term safety of DHEA has not been well studied.[30]

Melatonin Melatonin is a hormone that is produced by the pineal gland, retina, and gastrointestinal tract. Its production is inhibited by light so it is involved in regulating the body's cycles of sleep and wakefulness. Melatonin levels decline with age. Melatonin is a strong antioxidant and the decline in melatonin levels with age has been suggested to contribute to damage by free radicals.[31] Supplemental melatonin has been found to improve sleep patterns in older adults, but there is no evidence that it affects other aspects of aging.[32]

Insulin One of the most common hormone-related changes that occurs with aging is elevated blood glucose. This is due to both a decrease in the amount of insulin released by the pancreas and a decrease in the sensitivity of body tissues to insulin. Insulin resistance is related to poor diet, inactivity, increased abdominal fat mass, and decreased muscle mass. Almost one-third of U.S. adults over age 60 have diabetes, of which approximately half are undiagnosed.[33] Individuals with diabetes are treated with diet modification, increased exercise, oral medications, and, when necessary, injection of insulin.

Changes in Immune Function With age, many aspects of immune function decline while others become overactive.[34] The decline in immune function impairs the ability to fight disease, increasing susceptibility to and prolonging recovery from infections, reducing the effectiveness of immunizations, and increasing the risk of most types of cancer (Figure 16.8). Overactivity of the immune system causes increases in autoimmune disorders and inflammation. The presence of infections and chronic disease contributes to malnutrition (see Figure 16.5). In some older individuals nutritional deficiencies exacerbate the decline in immune function. The immune response depends on the ability of cells to differentiate, divide rapidly, and secrete immune factors, so nutrients that are involved in cell differentiation, cell division, and protein synthesis can influence the immune response. Nutrient deficiencies are common in older adults, including deficiencies of zinc, iron, folic acid, and vitamins B_6, B_{12}, C, D, and E. In individuals who are deficient, supplements of some nutrients can improve immune function, but the effect of these supplements on immune function in adequately nourished individuals may be helpful or harmful. For example, supplements of vitamin E above the recommended amount have been shown to enhance immune function. Zinc supplements at recommended levels can reduce the risk of infection, but intake above the recommended level can impair immune function. Omega-3 fatty acid supplements can help prevent autoimmune and inflammatory diseases but increase the risk of infections.[34]

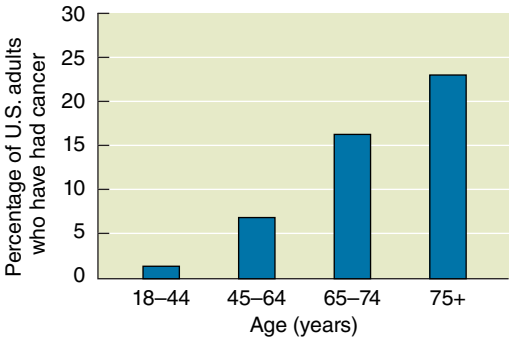


FIGURE 16.8 Effect of age on cancer incidence
The incidence of cancer increases with age.[35] One reason for the higher incidence is that the immune system's ability to destroy cancer cells declines. Reduced immune function also increases the frequency of infectious diseases and reduces the ability to recover from these diseases.

Why Medical Conditions Contribute to Malnutrition

The reduction in reserve capacity and decline in immune function that occur with age make infectious disease more frequent and more serious in the elderly. In addition, most older adults have at least one chronic medical condition. The incidence of cardiovascular disease, diabetes, osteoporosis, hypertension, cancer, arthritis, and Alzheimer's disease all increases with age. Some of these diseases change nutrient requirements, some decrease the appeal of food, and some impair the ability to obtain and prepare an adequate diet by affecting mobility and cognition. All of these can increase the risk of **food insecurity** and malnutrition.

food insecurity An inability to consistently acquire foods that are nutritionally adequate and individually, socially, and culturally acceptable.

Conditions That Decrease Mobility More than half of the older population suffers from some form of physical disability, and the incidence increases with advancing age. About 28% of older adults have disabilities that make it difficult to carry out the activities of daily life.[14] These limitations can affect the ability to maintain good nutritional health by making it hard to shop, prepare food, get around the house, or go out to eat. Arthritis, a condition that causes pain upon movement, is the most common cause of disability in older individuals (Figure 16.9).[36] Osteoporosis and its associated fractures can also affect mobility, which in turn affects the ability to acquire and consume a healthy diet.

Conditions That Impair Cognition Altered cognition can affect nutrition by interfering with the response to hunger and the ability to eat and to obtain and prepare food. Although many individuals maintain normal cognitive function into old age, the incidence of dementia increases with age. **Dementia** refers to an impairment in memory, thinking, and/or judgment that is severe enough to cause personality changes and affect daily activities and relationships with others. Causes of dementia include multiple strokes, alcoholism, dehydration, medication side effects and interactions, nutrient deficiencies, and **Alzheimer's disease**.

dementia A deterioration of mental state resulting in impaired memory, thinking, and/or judgment.

Alzheimer's disease A disease that causes the relentless and irreversible loss of mental function.

Low levels of vitamin B_{12} have also been suggested to affect cognitive function in the elderly. About 6 to 12% of older adults have vitamin B_{12} deficiency.[36] The main causes are poor dietary intake and poor absorption. Low serum levels of vitamin B_{12} are associated with cognitive impairment and degenerative neurological disease. Supplements of vitamin B_{12} can improve cognition, but only in patients with vitamin B_{12} deficiency.[38,39]

The relationship between vitamin E and cognitive impairment is controversial. In the elderly, higher blood levels of vitamin E have been associated with a lower risk of cognitive impairment, and those who suffer from dementia have lower plasma levels of vitamin E.[40]

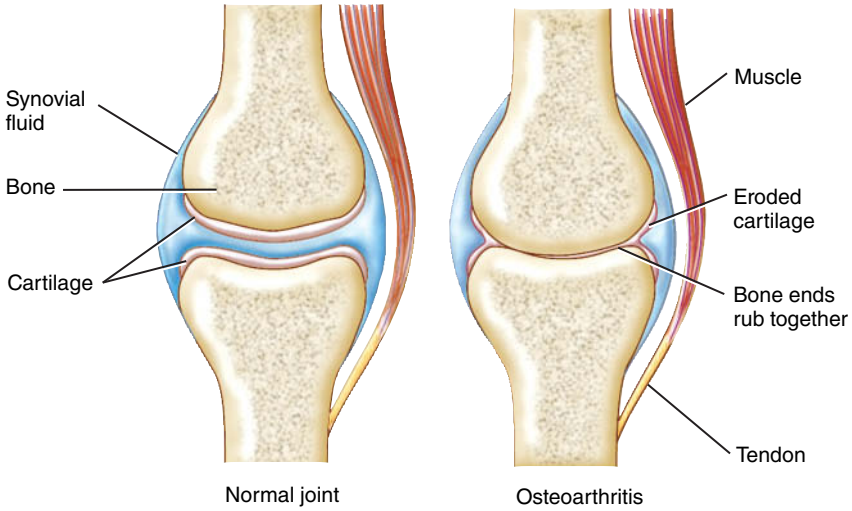


FIGURE 16.9 Osteoarthritis
Osteoarthritis, the most common form of arthritis, occurs when the cartilage that cushions the joints degenerates, allowing the bones to rub together and cause pain. Anti-inflammatory medications help reduce the pain. Supplements of glucosamine and chondroitin are marketed to improve symptoms and slow the progression of osteoarthritis, but clinical studies on the effect of these supplements on pain and function have been equivocal.[37]

Although there is no evidence that vitamin E supplements are beneficial in the treatment of Alzheimer's disease or mild cognitive impairment,[41] supplements of vitamin E combined with vitamin C and ß-carotene have been found to improve cognition in healthy elderly subjects.[42]

Over half of the cases of dementia in the elderly are due to Alzheimer's disease. The brains of patients with Alzheimer's disease are characterized by the accumulation of an abnormal protein and a loss of certain types of nerve cells. The cause of Alzheimer's disease is unknown, but there does appear to be a genetic component in some cases. One controversial theory is that accumulation of aluminum in the brain contributes to Alzheimer's disease. While the brains of patients with Alzheimer's do contain high levels of aluminum, it is not clear whether this is a cause of Alzheimer's. Nonetheless, some recommend reducing aluminum exposure from food, skin care products, antiperspirants, and pharmaceuticals.[43] The brains of patients with Alzheimer's also show damage from oxidative stress, and antioxidants are hypothesized to play a role in preventing and delaying the progression of Alzheimer's disease. Dietary patterns that include plenty of fruits, vegetables, fish, nuts, and legumes, and lower intakes of meats, high-fat dairy, and sweets seem to be associated with a reduced risk of Alzheimer's disease.[44] Low levels of antioxidant nutrients have been found in Alzheimer's patients, but it is unclear whether this is a cause or a consequence of the disease. Supplements have not been found to delay disease progression.[36]

Prescription and Over-the-Counter Medications The use of prescription and over-the-counter medications can affect nutritional status in a number of ways. Because health problems increase with increasing age, older adults are more likely to take medications; over 35% of nonhospitalized men and women 75 to 85 years of age take five or more prescription medications (Figure 16.10).[45] The more medications taken, the greater the chance of side effects such as increased or decreased appetite, changes in taste, constipation, weakness, drowsiness, diarrhea, and nausea that can affect nutritional status. Illness related to incorrect doses or inappropriate combinations of medications is also a significant health problem in the elderly. Both the effects of drugs on nutritional status and the effects of nutritional status on the effectiveness of the medications must be considered. Many older adults also take a variety of dietary supplements.[45] Some are harmful alone or in combination with prescription or over-the-counter medications.[46]

How Medications Affect Nutritional Status Medications can affect nutritional status by altering appetite, nutrient absorption, metabolism, or nutrient excretion (Table 16.2). The impact is greatest in individuals who must take medications for extended periods, those who take multiple medications, and those whose nutritional status is already marginal.

Some medications directly affect the gastrointestinal tract. More than 250 drugs, including blood pressure medications, antidepressants, decongestants, and the pain reliever ibuprofen (found in Advil, Motrin, and Nuprin), can cause mouth dryness, which can decrease interest in eating by interfering with taste, chewing, and swallowing. Aspirin is a stomach irritant and can cause small amounts of painless bleeding in the gastrointestinal tract, resulting in iron loss. Digoxin, which is a heart stimulant, can cause gastrointestinal upset, loss of appetite, and nausea. Narcotic pain medications such as codeine can lead to constipation, nausea, and vomiting.

Other drugs can decrease nutrient absorption. Cholestyramine (Questran), which is used to reduce blood cholesterol, and Orlistat and Alli, used to promote weight loss, can decrease the absorption of fat-soluble vitamins, vitamin B_{12}, iron, and folate. Antacids that contain aluminum or magnesium hydroxide (Rolaids or Maalox) combine with phosphorus in the gut to form compounds that cannot be absorbed; chronic use can result in loss of phosphorus from bone and possibly accelerate osteoporosis. Repeated use of stimulant laxatives can deplete calcium and potassium. Mineral oil laxatives prevent the absorption of fat-soluble vitamins.

Jose Luis Pelaez/Getty Images, Inc.

FIGURE 16.10 Multiple medications
It is common for older adults to take multiple medications daily.

TABLE 16.2 Commonly Used Drugs That May Contribute to Nutritional Deficiencies[47]

Drug group	Drug	Potential deficiency
Antacids and other acid-reducing agents	Sodium bicarbonate	Folate, iron, potassium
	Aluminum hydroxide	Calcium, phosphorus
	Ranitidine (Zantac)	Iron, zinc
	Cimetidine (Tagamet)	Iron, zinc, folic acid, vitamin B_{12}, vitamin D
Antimicrobial agents	Tetracycline	Calcium, potassium, magnesium, folate, riboflavin, vitamins B_6, B_{12}, C, K
	Gentamicin	Calcium, potassium, magnesium, vitamin B_6
	Neomycin	Fat, folic acid, iron, calcium, magnesium, potassium, vitamins B_6, B_{12}, A, D, K
	Trimethoprim	Calcium, folate, magnesium, vitamins B_6, B_{12}, K
Anti-inflammatory agents	Sulfasalazine	Folate
	Prednisone	Calcium
	Aspirin	Vitamin C, folate, iron, vitamin E, potassium
Anticoagulant drugs	Warfarin	Vitamin K
Antihypertensive drugs	Hydralazine	Vitamin B_6
Diuretics	Thiazides	Potassium, magnesium, zinc
	Furosemide	Potassium, calcium, magnesium, thiamin, vitamins B_6, C
Hypocholesterolemic agents	Cholestyramine	Fat-soluble vitamins, β-carotene, iron, calcium, magnesium, phosphorus, zinc, folate, vitamin B_{12}
	Statins	Selenium, vitamin E, β-carotene
Laxatives	General	Potassium
	Mineral oil	Fat-soluble vitamins, β-carotene, calcium, phosphorus, potassium
Tranquilizers	Chlorpromazine	Riboflavin

The metabolism of drugs can also affect nutritional status. For example, anticonvulsive drugs (used to prevent seizures) increase the liver's capacity to metabolize and eliminate vitamin D, therefore increasing the need for vitamin D.

Some drugs affect nutrient excretion. Diuretics, which are used to treat hypertension and edema, cause water loss, but some types (thiazides) also increase the excretion of potassium. People taking thiazide diuretics are advised to include several good sources of potassium in their diet each day or are prescribed supplements.

How Food and Nutritional Status Affect Drug Absorption and Metabolism Food components can either enhance or retard the absorption and metabolism of drugs. Some drugs, such as the pain medication Darvon, are absorbed better or faster if taken with food. Other drugs, such as aspirin and ibuprofen, should be taken with food because they are irritating to the gastrointestinal tract. Because food can delay how quickly drugs leave the stomach, some medications are best taken with just water. Other drugs interact with specific foods. For instance, the antibiotic tetracycline should not be taken with milk because it binds with calcium in the gastrointestinal tract, making both unavailable. The metabolism of statins, drugs taken to lower cholesterol, is blocked by a compound in grapefruit, so eating grapefruit or drinking grapefruit juice can result in drug toxicity.[48]

Nutritional status can also affect drug metabolism. If nutritional status is poor, the body's ability to detoxify drugs may be altered. For example, in a malnourished individual, theophylline, used to treat asthma, is metabolized slowly, resulting in high blood levels of the drug that can cause loss of appetite, nausea, and vomiting.

Specific nutrients can also affect the metabolism of drugs. High-protein diets enhance drug metabolism in general, and low-protein diets slow it. Vitamin K hinders the action of anticoagulants taken to reduce the risk of blood clots. On the other hand, omega-3 fatty acids, such as those in fish oils, inhibit blood clotting and may intensify the effect of an anticoagulant drug and cause bleeding. It is safe to eat fish while taking anticoagulant drugs; however, the use of fish oil supplements is not recommended. Drugs can also interact with one another. For example, alcohol affects the metabolism of over 100 medications. Drug interactions can exaggerate or, in some cases, diminish the effect of a medication. Individuals taking any medication should consult their doctor, pharmacist, or dietitian regarding how the drug could affect the action of other

drugs they may be taking, how the drug could affect their nutrition, and how their nutrition could affect the action of the drug.

How Economic, Social, and Psychological Factors Affect Nutritional Status

A variety of economic, social, and psychological problems may complicate the nutritional health of older adults. Many of these are interrelated and impair nutritional health by decreasing the motivation to eat and the ability to acquire and enjoy food.

Low Income Over 4.2 million older adults live below the poverty level.[14] Poverty is more prevalent among elderly African Americans and Hispanics. About 7.4% of elderly Caucasians live below the poverty level, compared to 17.6% of elderly African Americans and 19.8% of elderly Hispanics. Many older adults must live on a fixed income when they retire from their jobs, making it difficult to afford health care, especially medications, and a healthy diet. Food is often the most flexible expense in one's budget, so limiting the types and amounts of foods consumed may be the only option available for older adults trying to meet expenses. Substandard housing and inadequate food preparation facilities can make the situation worse because food cannot easily be prepared and eaten at home.

Dependent Living Although many older adults continue to live independently in their own homes, the physical decline and psychological issues associated with aging cause some to eventually require assistance in living (Figure 16.11). Poor eyesight and other physical restrictions can limit the ability to drive a car. Without help, many older adults may be unable to get to markets and food programs, restricting the types of food available to them. While a social support system consisting of family members, friends, and other caregivers can help many people stay in their own homes, others may require assisted-living facilities, where they have their own apartments but can obtain assistance around the clock. For some, however, a nursing home is required to obtain the appropriate care.

Individuals in nursing homes are at increased risk for malnutrition because they are more likely to have medical conditions that increase nutrient needs and that interfere with food intake or nutrient absorption, and because they are dependent on others to provide for their care. In addition, 50% of institutionalized elderly suffer from some form of disorientation or confusion, which further increases the likelihood of decreased nutrient intake. Even when adequate meals are provided, many nursing home residents require assistance in eating and frequently do not consume all of the food served, increasing the likelihood of fluid and energy deficits.

THINK CRITICALLY

Why does a limited ability to walk increase the risk of malnutrition?

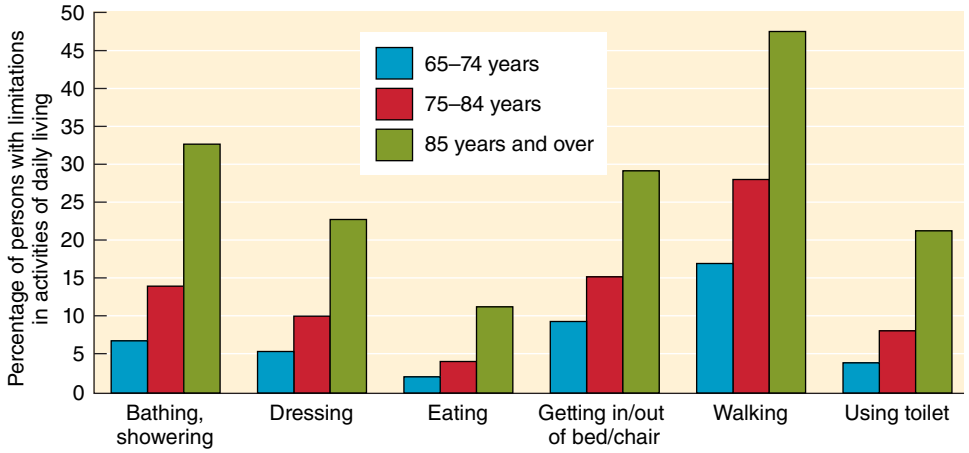


FIGURE 16.11 Percentage of persons with limitations in activities of daily living.[49] As people get older, they are more likely to need assistance with the basic activities of daily living, such as eating, dressing, and bathing. These physical limitations restrict their ability to acquire and consume a healthy diet.

Depression Major depression occurs in 1 to 5% of older adults. The incidence increases with psychosocial changes and poor health.[50] Social factors such as retirement and the death or relocation of friends and family can cause social isolation and depression. Medical factors such as disease and disability cause depression and reduce the ability to engage in normal daily activities, visit with friends and family easily, and provide for personal needs. This loss of independence further contributes to depression. The incidence of major depression in older adults increases to 13.5% in those who require home health care and to 11.5% in those who are hospitalized.[50] Nutritional factors such as vitamin D deficiency can also contribute to depression.[51] Depression, in turn, can make meals less appetizing and decrease the quantity and quality of foods consumed, thereby increasing the risk of malnutrition.

16.4 Nutritional Needs and Concerns of Older Adults

LEARNING OBJECTIVES

- Compare the energy needs of older adults to those of young adults.
- Describe why older adults are at risk for dehydration.
- List the vitamins and minerals for which older adults are at risk for deficiency.

Older adults are a diverse population. Some 70-year-olds are running marathons while others are confined to wheelchairs. The physiological and health changes that accompany aging affect the requirements for some nutrients, how nutrient needs must be met, and the risk of malnutrition. To best address the nutrient needs of adults, the DRIs divide adulthood into four age categories: young adulthood, ages 19 through 30; middle age, 31 through 50 years; adulthood, ages 51 through 70; and older adults, those over 70 years of age. Recommendations have been developed to meet the needs of the majority of healthy individuals in each age group. Although the incidence of chronic diseases and disabilities increases with advancing age, these conditions are not considered when making general nutrient intake recommendations.

Energy and Macronutrient Needs

Adult energy needs typically decline with age. A large part of this decrease can be attributed to inactivity.[36] Inactivity lowers energy requirements directly by lowering energy expenditure and indirectly by causing a decline in lean body mass. This decrease in lean body mass contributes to the decrease in basal metabolic rate (BMR) that occurs as adults get older. There is a 2 to 3% drop in BMR every decade after about age 20. The thermic effect of food also declines with age and is about 20% lower in older than in younger adults. These decreases are reflected in the energy needs of older adults. For example, the estimated energy requirement (EER) for an 80-year-old man is almost 600 kcal/day less than that for a 20-year-old man of the same height, weight, and physical activity level.[38]

The lower energy needs of older adults put them at risk for nutrient deficiencies because the needs for vitamins, minerals, and protein remain constant or even increase. A nutrient-dense diet is necessary to meet nutrient requirements without exceeding energy needs. However, the diets of older adults are typically low in nutrient-rich food groups and higher in empty calories than recommended.[36]

Protein Protein is needed at all ages to repair and maintain tissues. Therefore, unlike energy requirements, the requirement for protein does not decline with age. The RDA for older adults is currently the same as for younger adults: 0.8 g/kg of body weight per day. However, evidence is accumulating that older adults need more protein than younger adults to support health, recover from illness, and maintain functionality.[52] Current protein recommendations do not consider changes in protein metabolism that reduce the ability of older adults to use protein or the presence of inflammation and medical conditions that increase

protein needs. To help maintain and regain lean body mass the PROT-AGE Study Group recommends that people over age 65 consume 1.0 to 1.2 g of protein per kilogram of body weight per day. A protein intake above 1.2 g/kg/day is suggested for those who are physically active and 1.2 to 1.5 g/kg/day is recommended for those with acute or chronic illnesses.[52] Inadequate protein intake contributes to sarcopenia, osteoporosis, and reduced immune function. Because of the decline in energy needs that occurs with age, to meet protein requirements older adults need to consume a diet that is higher in protein relative to energy intake than the diets of younger adults. Due to the diversity of older adults, the amount of protein each person needs will vary depending on his or her functional ability and medical conditions. The median protein intake for adults ages 71 and older in the United States is currently about 1 g/kg body weight per day.[53,54]

Fat The digestion and absorption of fat do not change with advancing age. Therefore, although total fat intake may be lower in older adults due to lower energy intake, the recommendations regarding the proportion and types of dietary fat apply to older as well as younger adults. A diet with 20 to 35% of energy from fat that contains adequate amounts of the essential fatty acids and limits saturated fat and *trans* fat is recommended. Following these recommendations will allow older adults to meet their nutrient needs without exceeding their energy requirements and may delay the onset of chronic disease. However, in certain situations, such as being underweight, greater fat intake may be warranted.

Carbohydrates and Fiber As with fat, the recommended proportion of energy from carbohydrate (45 to 65% of energy) does not change with age, but the total amount needed may be lower in older adults due to lower energy needs. Dietary carbohydrate should come from whole grains, fruits, vegetables, and low-fat dairy products, and foods high in added sugars should be limited. This pattern will help ensure adequate nutrients without excess energy.

The recommendations for fiber intake for older adults are slightly lower than those for younger adults because the AIs for fiber are based on total energy needs.[38] Despite the slightly lower AI, fiber intake in older adults is still below recommendations.[36] High-fiber foods such as whole grains, fruits, vegetables, and legumes also provide vitamins, minerals, and phytochemicals, and when consumed with adequate fluid, help prevent constipation, hemorrhoids, and diverticulosis—conditions that are common in older adults. High-fiber diets may also be beneficial in the prevention and management of diabetes, cardiovascular disease, and obesity.

Water The recommended water intake for older adults is the same as that for younger adults;[55] however, changes in the homeostatic mechanisms that regulate water balance may make meeting these needs more challenging. With age the sense of thirst decreases, which can reduce fluid intake. In addition, the kidneys are no longer as efficient at conserving water, so water loss increases. Other physical and psychological changes also increase the risk of dehydration. For instance, difficulty swallowing and restricted mobility may limit access to water even in the presence of thirst. Depression, which decreases water intake, and medications such as laxatives and diuretics, which increase water loss, also contribute to dehydration in the elderly. The elderly may also voluntarily restrict fluid intake to avoid accidents due to incontinence or because numerous trips to the bathroom increase pain from arthritis. In addition to impairing organ function, inadequate fluid intake contributes to the development of constipation. Many older adults do not consume the recommended amount of water and dehydration is a major problem, particularly in those over age 85 and in those who are institutionalized.[36]

Micronutrient Needs

Although the recommended intake for many of the micronutrients is no different for older adults than for younger adults, the decrease in energy intake that occurs with age causes a decline in the intakes of micronutrients, especially the B vitamins, calcium, iron, and zinc (**Figure 16.12**).[18] Changes in digestion, absorption, and metabolism also affect micronutrient status. In turn, inadequate levels of certain micronutrients contribute to the development of some of the disorders that are common in older adults.

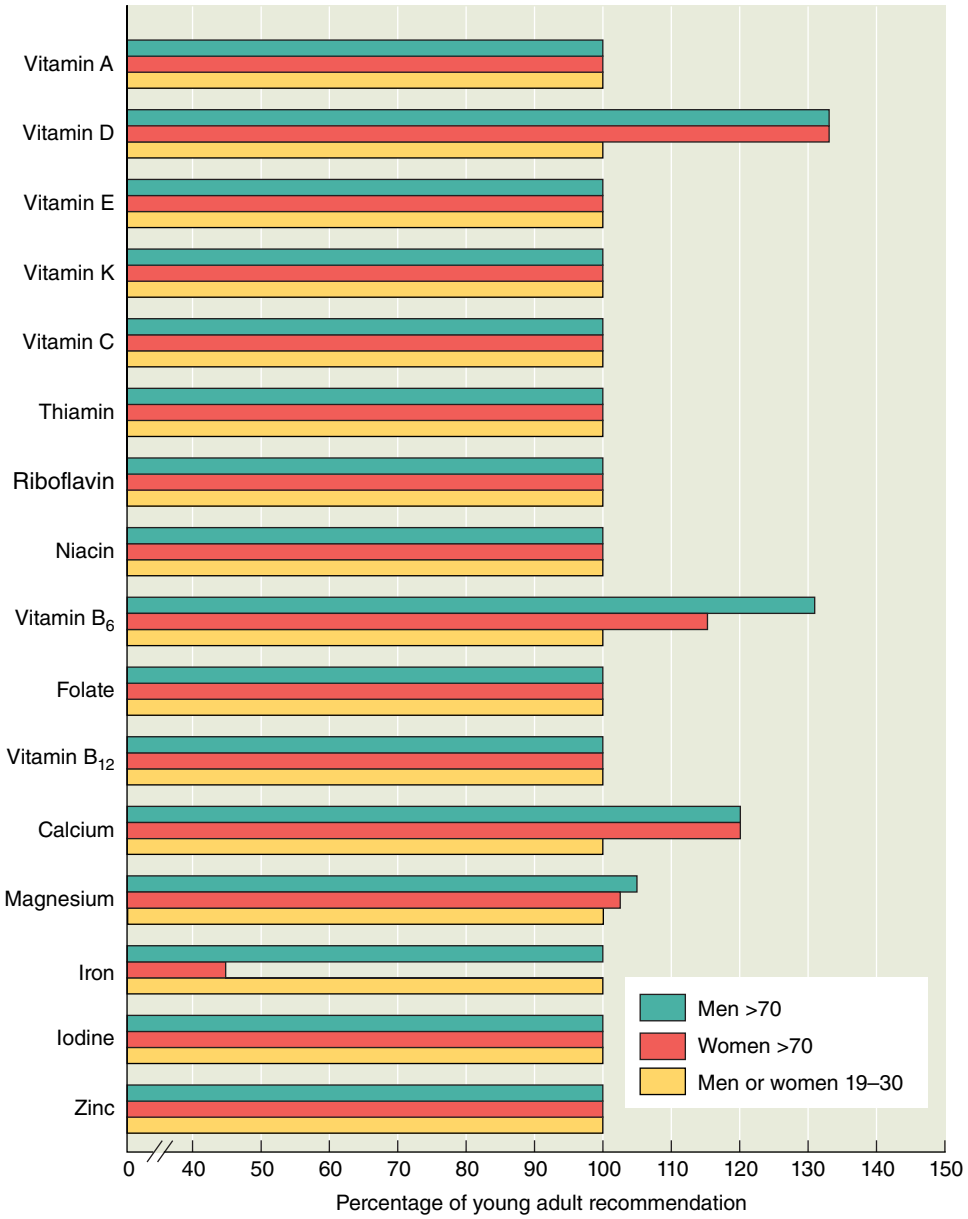


FIGURE 16.12 Vitamin and mineral needs of older adults This graph compares the recommended micronutrient intakes for young adults ages 19 through 30 to those of adults over age 70. The recommended amounts differ only for vitamin D, vitamin B_6, calcium, magnesium, and iron. The decreased iron needs of older women occur because iron is no longer lost through menstruation.

B Vitamins The only B vitamins for which recommendations differ between older and younger adults are vitamins B_6 and B_{12}. The RDA for vitamin B_6 is greater in people ages 51 and older than for younger adults because higher dietary intakes are needed to maintain the same functional levels in the body. The RDA for vitamin B_{12} is not increased for older adults, but it is recommended that individuals over the age of 50 meet their RDA for vitamin B_{12} by consuming foods fortified with vitamin B_{12}, such as breakfast cereals or soy-based products, or by taking a supplement containing vitamin B_{12}.[20] This is recommended because dietary intakes tend to be low in older adults, and for many absorption of the vitamin B_{12} naturally present in food is reduced by atrophic gastritis. The vitamin B_{12} in fortified foods and supplements is not bound to proteins, so it is absorbed even when stomach acid is low.

The RDA for folate is the same for adults of all ages, but folate intake is a concern in older adults for several reasons. Deficiencies of folate and vitamin B_{12} contribute to anemia, which is common in older adults. In addition, low folate, along with inadequate levels of vitamins B_6 and B_{12}, may result in an elevated homocysteine level, which increases the risk of cardiovascular disease. Due to the importance of folate in DNA synthesis, low folate intake has also been hypothesized to cause DNA changes that contribute to cancer development.[56] The fortification of enriched grain products with folate, which began in 1998, has

increased intake of this vitamin. However, when folate is consumed in excess it can mask the symptoms of vitamin B_{12} deficiency. Diets that include highly fortified products, such as breakfast cereals, and folate supplements may exceed the UL for folate. Levels above the UL increase the risk that vitamin B_{12} deficiency will be masked and therefore go untreated (see Chapter 8).[57]

Antioxidants The recommended intake of antioxidant vitamins is the same in older as in younger adults, but low dietary intakes of vitamins C and E and carotenoids are a concern due to low fruit and vegetable consumption among the elderly. Fruits and vegetables are good sources of antioxidants and higher intakes of these are associated with a lower risk of chronic disease and functional impairment in the elderly, yet less than half of individuals 65 years of age and older consume five or more servings of fruits and vegetables daily.[58]

Calcium and Vitamin D Low intakes of both calcium and vitamin D contribute to osteoporosis in the elderly. Calcium status is a problem in elderly people because calcium intake is low and intestinal absorption decreases with age. Without sufficient calcium, bone mass decreases, and the risk of bone fractures due to osteoporosis increases. The reduction in estrogen that occurs with menopause further increases bone loss in women by increasing the rate of bone breakdown and decreasing the absorption of calcium from the intestine. The RDA for adult men 51 years and older is 1000 mg/day. Because of the accelerated bone loss in women during the postmenopausal period, the RDA for women 51 years and older is increased to 1200 mg/day. To reduce age-related bone loss, the RDA for both men and women over 70 years of age is 1200 mg/day.[59]

Vitamin D, which is necessary for adequate calcium absorption, is also at risk of deficiency in older adults. Intake is often low, and synthesis in the skin is reduced due to limited exposure to sunlight and because the capacity to synthesize vitamin D in the skin decreases with age. The RDA for people ages 51 and older is 600 IU (15 μg)/day, the same as for younger adults. For individuals over age 70 years, the RDA is increased to 800 IU (20 μg)/day.[59]

Iron The iron needs of women decline sharply at menopause when blood loss through menstruation stops. The RDA for iron for women over 50 years of age is less than half of that of menstruating women (see Figure 16.12). The iron needs of men do not change. Nonetheless, iron deficiency anemia is common in the elderly, often due to chronic blood loss from disease and medications and poor iron absorption due to low stomach acid and antacid use.[60]

Zinc The RDA for zinc is not changed in older adults, but low dietary intakes as well as malabsorption, physiological stress, psychosocial factors such as depression, muscle wasting, and medication use can all contribute to poor zinc status.[61] The consequences of poor zinc status may include loss of taste acuity and impaired immune function and wound healing. Loss of taste acuity can contribute to malnutrition by reducing food intake. Reduction in immune function and wound healing increases the risk of infection, which can also impair nutritional status.

16.5 Keeping Older Adults Healthy

LEARNING OBJECTIVES

- Explain how exercise and a nutritious diet affect the degenerative changes of aging.
- Plan a menu that would meet your MyPlate recommendations if you were 80 years old.
- Describe the components of a healthy exercise program for an 80-year-old.
- List nutrients for which supplements are recommended to older adults.
- Describe the purpose of the DETERMINE checklist.

There is no secret dietary factor that will bestow immortality, but good nutrition and an active lifestyle are major determinants of successful aging. A good diet can extend an individual's healthy life span by preventing malnutrition and delaying the onset of chronic diseases. The diseases that are the major causes of disability in older adults—obesity, cardiovascular disease, hypertension, diabetes, cancer, and osteoporosis—are all nutrition related. A physically active life and healthy eating will not necessarily prevent these diseases, but they may slow the changes that accumulate over time, postponing the onset of disease symptoms. For example, the risk of developing cardiovascular disease can be decreased by physical activity and a diet low in saturated fat and *trans* fat, and high in whole grains, fruits, and vegetables. The risk of osteoporosis may be reduced by adequate calcium and vitamin D intake and physical activity throughout life. And the likelihood of developing certain types of cancer can be reduced by consuming a diet low in saturated fat and high in whole grains, vegetables, and fruits. Regular physical activity can slow the loss of lean body mass, maintain fitness and independence, and allow an increase in food intake without weight gain, so micronutrient needs are more easily met.

Despite the fact that the nutrient needs of older adults are not drastically different from those of young adults, it is more challenging to meet these needs. Some of this challenge is due to changes in health and social and economic conditions that are more common in this population. Meeting needs requires consideration of each person's medical, psychological, social, and economic circumstances. For some, government aid is needed to ensure adequate nutrition.

Maintaining a Healthy Weight

Weight management is a balancing act in older adults. Weight loss and low body weight increase the risk of malnutrition, sarcopenia, osteoporosis, and overall morbidity and mortality. On the other hand, obesity impairs physical function, decreases the quality of life, and increases the risk of chronic diseases and overall mortality. Therefore, being overweight or mildly obese may be beneficial for older adults; it has been found to decrease overall mortality in this age group.[62] Weight loss in overweight/obese older adults improves physical functioning, arthritis, type 2 diabetes, and heart disease, but also has a downside because it is associated with a loss of muscle and bone mass.

Weight management in older adults should focus on lifestyle changes that improve physical function and quality of life and that maintain or increase lean body mass and muscular strength.[62] Rather than weight loss, overweight individuals may benefit from a plan to maintain their weight while increasing lean body mass through physical activity. In individuals who are obese, moderate weight loss can decrease obesity-related complications. Including exercise as part of a weight-loss or weight-maintenance regimen can improve strength, endurance, physical function, and overall well-being.

How to Plan a Healthy Diet for Older Adults

The first step toward meeting the nutrient needs of the elderly is to plan a healthy diet. Because older adults need less energy but the same or greater amounts of most micronutrients, their food choices must be nutrient dense. Meals and snacks should include plenty of liquids because dehydration is a common problem. In some cases, nutrient supplements may be necessary to meet needs.

A MyPlate Daily Food Plan A MyPlate Daily Food Plan can be used to determine the recommended amounts of food from each group needed to meet, but not exceed, energy needs of older as well as younger adults (**Figure 16.13**). To meet micronutrient and protein needs without exceeding calorie needs, older adults need to choose nutrient-dense foods from each food group. Choosing a variety of fruits and orange, dark green, and starchy vegetables will maximize vitamin and phytochemical intake. Lean protein sources such as lean meat, seafood, legumes, and reduced-fat dairy products will help meet protein and calcium needs. To ensure adequate fiber, whole grains should be chosen from the grains group. To ensure foods

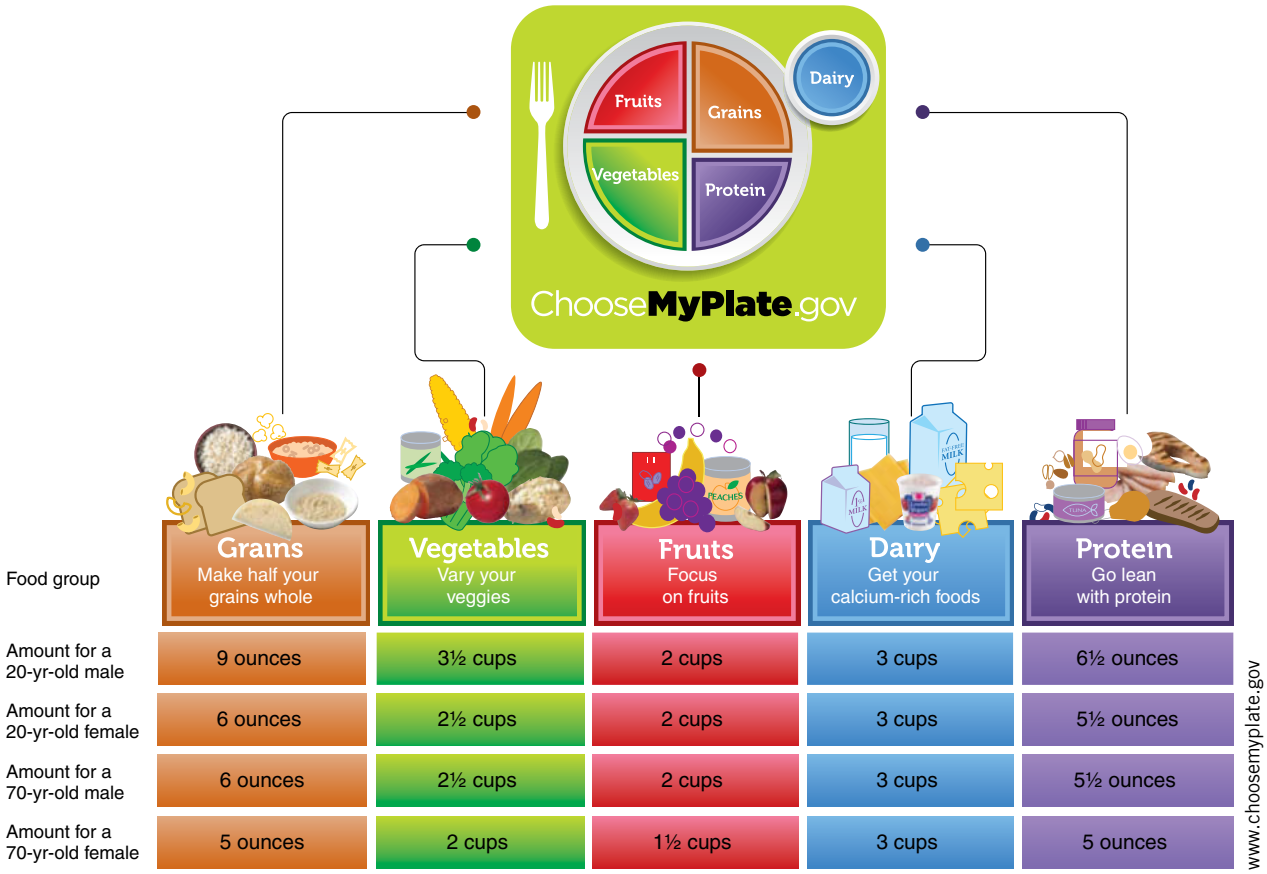


FIGURE 16.13 MyPlate recommendations
The MyPlate recommendations shown here are for 20- and 70-year-old men and women who get less than 30 minutes of activity per day. The older adults need to consume fewer servings from most food groups and are allotted fewer empty calories: only 120 kcal/day for a 70-year-old woman and 260 kcal/day for a 70-year-old-man compared to 260 and 360 kcal/day, respectively, for their 20-year-old counterparts.

THINK CRITICALLY

Why do 70-year-olds need to eat a more nutrient-dense diet than 20-year-olds?

are eaten, those offered should be easy to prepare, easy to eat, and well seasoned to enhance appeal. In older adults, there is room for even fewer empty calories than in younger adults (see Figure 16.13).

Dietary Supplements Many older adults may benefit from supplementing particular nutrients. Vitamin D supplements may be advantageous because production of this vitamin in the skin is decreased in the elderly and exposure to sunlight may be limited. A calcium supplement may be necessary to meet needs, particularly in older women, because it can be difficult to consume 1200 mg of calcium from food without exceeding energy needs. Supplemental vitamin B_{12} from pills or fortified foods is recommended for older adults because the absorption of vitamin B_{12} often decreases with age. Supplemental protein in the form of a liquid nutritional supplement, such as Ensure or Boost, may be needed to ensure adequate protein in those who are limited in their ability to chew and swallow meat and other high-protein foods. However, supplements should not take the place of a balanced, nutrient-dense diet high in whole grains, fruits, and vegetables. These foods also contain phytochemicals and other substances that may protect against disease. Older adults should be cautious to avoid overdoses, and the resulting toxicities, when selecting nutrient supplements. Supplements of nonnutrient substances should be taken with care. Most of these provide no proven benefit, many are costly, and some can be toxic (see **Debate: Are Herbal Supplements Helpful or Harmful?**).

The hypothesis that oxidative damage contributes to aging has fueled the popularity of antioxidant supplements. Although there is evidence that diets high in antioxidants from fruits and vegetables and other plant foods are associated with a reduced incidence of various

DEBATE

Are Herbal Supplements Helpful or Harmful?

Herbal supplements are popular as "natural" remedies and are commonly used by older adults. Are these products a helpful addition to traditional health care, or are they a health risk?

Many cultures, including the ancient Greeks and Native Americans, have used herbal products to treat everything from coughs, constipation, and poison ivy to arthritis and heart ailments. Today, about one in six Americans uses herbs to treat maladies or boost health.[63] These products are affordable and widely available, and they do not require prescriptions. Advocates of herbal supplements feel that this availability allows people more control of their own health care. Opponents fear that self-dosing with herbs may lead to toxic reactions and prevent people from seeking traditional medical care and proven treatments. How effective and safe are herbal supplements?

Catherine Karnow/NG Image Collection

Herbs have demonstrated physiological effects. In fact, some of the prescription drugs used today were derived from plants. Aspirin comes from willow bark; digitalis, a drug prescribed for certain heart conditions, comes from foxglove leaves. Herbs are made from all or part of the plant, so the amounts of active ingredients are affected by growing conditions, harvesting, and processing, and they vary with the brand and batch.[64] In contrast, drugs are purified compounds and are tested to ensure consistent amounts in each pill. Advocates believe that having a mixture of compounds is an advantage because some ingredients can enhance the effects of others. Opponents argue that these interactions may be negative, diminishing the effect of one of the active ingredients.[64]

Proponents of herbal supplements argue that most herbal medicines are well tolerated and have fewer unintended consequences than prescription drugs. Prescription drugs are certainly not without side effects, but because of the levels of regulation, we are assured that a prescribed drug is an effective treatment, and any side effects are documented. Herbal products, like other dietary supplements, do not require FDA approval before they are marketed. Opponents believe that this lack of regulation allows dangerous products to enter the marketplace. A study that tested the quality of herbal supplements found that a third of those tested did not contain the botanical listed on the label, and almost 60% were contaminated with substances not included on the label.[65] Some botanical compounds themselves are toxic. The FDA has issued warnings about ingredients such as comfrey, kava, and aristolochic acid, and it took ephedra off the market.[66] Because herbal products are made from unpurified plant material, there is also a risk of contamination with pesticides, microbes, metals, and other toxins.[67]

Another concern when people self-dose with herbs is that the herbs may interact with drugs and cause unwanted side effects.[63] For example, gingko biloba and garlic can interfere with blood clotting, and so should not be used with blood-thinning medication or before surgery. St. John's wort may interact with anesthetics and antidepressants, and echinacea can limit the effect of some steroids.[68] Prescription drugs come with instructions and warnings about potential side effects; in addition, a physician or pharmacist considers the other medications and conditions that may alter the safety and effectiveness of the drug, and a prescribing physician monitors patient health. This is not the case with dietary supplements.

Herbs are medicines and, as with taking other medications, taking herbs has some advantages and risks. Whether herbal supplements are helpful or harmful depends on the supplement, the dose, and the consumer.

THINK CRITICALLY: Would you purchase a remedy from the selection of herbs at the shop shown in this photo? Why or why not?

chronic diseases, including cardiovascular disease and some types of cancer, intervention trials have not consistently found that antioxidant supplements reduce the risk of chronic disease or decrease mortality (see Chapter 12, *Debate: Antioxidant Supplements: Helpful or Harmful?*).[69] So, rather than taking an antioxidant supplement, older adults, like everyone else, should consume a diet plentiful in plant foods high in these nutrients. When antioxidant nutrients are obtained from foods, they bring with them phytochemicals, some of which offer additional

© Charles D. Winters

FIGURE 16.14 Foods high in antioxidants
Older adults can avoid antioxidant deficiencies by consuming a variety of foods that are good sources of antioxidant nutrients. These also provide fiber, energy, other micronutrients, and phytochemicals.

antioxidant protection and others of which protect us from chronic disease in other ways (Figure 16.14).

Physical Activity for Older Adults

Regular physical activity can extend the years of active independent life, reduce disability, and improve the quality of life for older adults. It helps to maintain muscle mass, bone strength, cardiorespiratory function, and balance. It lowers the risk of chronic diseases such as cardiovascular disease, diabetes, and cancer, reduces depression, and improves cognitive function.[36] Exercise also increases energy expenditure, so more food can be eaten, increasing the chances that adequate amounts of all essential nutrients will be consumed and reducing the risk of weight gain. To maximize the benefits of exercise, a physical activity program for older adults should include activities that improve endurance, strength, flexibility, and balance and be geared to the physical ability of the individual (Table 16.3).[70,71]

How to Get Started Before starting an exercise program or increasing the level of physical activity, older adults should check with their physician. Those who have been inactive should begin with very low-intensity physical activities. To maximize enjoyment and optimize adherence, activities should be tailored to the individual's needs and interests. Exercise classes or other group-based activities can be a good way for older adults to start an exercise program. Classes enhance social interaction and improve compliance by fostering a mutual commitment to continuing the activity. Classes also provide instruction on proper technique, which can minimize injuries, and supervision in the event of an injury or other emergency.

Increasing Endurance Endurance activities appropriate for older adults include low-impact aerobic activities such as walking, biking, and swimming. These aerobic activities provide protection against chronic disease; the benefit increases if intensity increases from low to moderate. Water activities such as water aerobics and swimming do not stress the joints, so they can be used to improve endurance in those with arthritis or other bone and joint disorders (Figure 16.15). Some weight-bearing exercise, such as walking, is encouraged to promote bone health. Safe walking environments include shopping malls or lighted sidewalks. Lifestyle activities such as vacuuming, sweeping, mopping, and gardening can also enhance endurance. To provide benefits, endurance activities need to be performed for at least 10 minutes without rest.

TABLE 16.3 Exercise Guidelines for Older Adults[70,71]

• All older adults should avoid inactivity. Some physical activity is better than none, and older adults who participate in any amount of physical activity gain some health benefits.
• For substantial health benefits, older adults should engage in at least 150 minutes a week of moderate-intensity, or 75 minutes a week of vigorous-intensity aerobic physical activity, or an equivalent combination.
• Aerobic activity should be performed in episodes of at least 10 minutes and preferably spread throughout the week.
• For additional health benefits, older adults should increase their aerobic physical activity to 300 minutes a week of moderate-intensity, or 150 minutes a week of vigorous-intensity aerobic physical activity, or an equivalent combination.
• Older adults should engage in muscle-strengthening activities that are moderate or high intensity and involve all major muscle groups on two or more days a week.
• Older adults should include exercises that incorporate balance, coordination, agility, and proprioception.
• Older adults whose activity is limited by chronic conditions should be as physically active as their abilities and conditions allow.
• Older adults with chronic conditions should discuss their limitations with their health-care providers in order to understand whether and how their conditions affect their ability to participate in regular physical activity safely.

Building Strength Resistance training has been shown to increase strength and lean body mass as well as to slow the decrease in bone density common in the elderly. Muscle-strengthening exercise should be performed two or more days per week.[71] Lifting small weights or stretching elastic bands at a level that requires some physical effort can provide strength training (Figure 16.16). Weight machines and calisthenics can also be used to increase strength. Both upper- and lower-body muscles should be included in a strengthening regimen. Muscles of the lower body are particularly important for maintaining mobility and independence.

Photo and Co/Getty Images, Inc.

FIGURE 16.15 Low-impact activities
Water aerobics classes provide older adults with a low-impact aerobic activity and social interaction.

Improving Flexibility Flexibility decreases with age but can be improved with exercise. Better flexibility enhances postural stability and balance, makes the tasks of everyday life easier, and may reduce the risk of injuries.[70,71] Flexibility exercises should include dynamic stretching, which moves the muscle through a full range of motion, as well as static stretches, which extend a muscle its full length and hold it for 10 to 30 seconds. The movements should be smooth and stretches held steady without bouncing. Stretching can be incorporated into lifestyle activities such as putting away the dishes on high and low shelves and tying shoes.

Maintaining Balance Improvements in strength and endurance also improve balance, but specific neuromotor exercise should be included in an exercise program for older adults.[70] This type of exercise helps improve physical function and reduce the risk of falls by improving balance, as well as agility, coordination, and proprioception, which is the ability to sense the position, orientation, and movement of the body and its parts. Neuromotor exercises should include those that improve balance and coordination while standing still, such as balancing on one leg or standing upright with the eyes closed, and those that improve balance, agility, and coordination while moving around, such as walking along a straight line or heel-to-toe walking. Balance activities can also be incorporated into daily routines, for example, standing on one foot while waiting in line at the grocery store. Yoga and tai chi are examples of activities that combine neuromotor exercise, resistance exercise, and flexibility exercise.

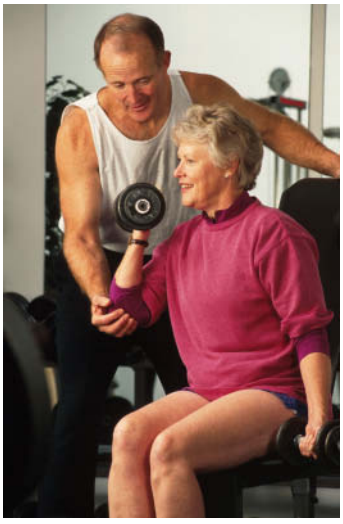
How to Prevent Food Insecurity

Older adults who are food insecure are more likely to have lower intakes of energy and essential nutrients, be in poor health, and have limitations in the activities of daily living.[36] Preventing food insecurity and ensuring adequate nutrient intake may involve providing nutrient-dense meals and instruction regarding nutrient needs, economical food choices, and how to prepare food. It may also require assistance with shopping and food preparation.

Overcoming Economic and Social Limitations Affording a healthy diet is a problem for many older individuals. Reduced-cost food and meals at senior centers, food banks, and soup kitchens are available to people on limited incomes, as are coupons and debit cards that can be used to purchase food. Programs that provide education about low-cost, nutritious food choices can also help reduce food costs.

A social problem that contributes to poor nutrient intake is loneliness (Figure 16.17). Living, cooking, and eating alone can decrease interest in food. This can be a problem not only for the elderly but for anyone who typically eats alone.

Cooking for one is also a challenge. Buying single servings of food is an option, although it can be expensive. To avoid spoilage of perishable items, grocers can be asked to break up packages of meat, eggs, fruits, and vegetables so small amounts can be purchased. Alternatively, large packages can be purchased and shared among friends. Cooking larger portions and freezing foods in meal-size batches can be helpful not only with cost but also to



© Ingram Publishing/Alamy Images

FIGURE 16.16 Muscle-strengthening exercise
Resistance training at any age improves muscle strength and endurance.

Thinkstock/Getty Images, Inc.

FIGURE 16.17 Congregate meals
The social interaction provided by congregate meals is as beneficial to older adults as the meals provided.

relieve the boredom of eating the same leftovers several days in a row. Creativity and flexibility in what defines a meal can also help. An easy single meal can be prepared by topping a potato with cooked vegetables and cheese, or with leftover chili or spaghetti sauce (Figure 16.18). Yogurt or a bowl of cereal with fruit and milk is also a nutritious dinner option.

Overcoming Physical Limitations Limited mobility may reduce food intake by making shopping and cooking difficult. For those who have difficulty getting to the store, programs are now available for ordering food by phone and having it delivered; however, this is not always an affordable option. For those who have difficulty cooking, precooked foods, frozen dinners, canned foods, or salad-bar items, as well as instant foods such as cereals, rice and noodle dishes, and soups that just require adding water, can provide a meal with almost no preparation. Medical nutritional products such as Ensure or Boost can also be used to supplement intake. These fortified products have a long shelf life and can meet nutrient needs with a small volume. Eating out at senior centers or low-cost restaurants or sharing shopping and cooking chores with a friend can reduce cooking demands and increase social interaction. Home health services can help with cooking and feeding, and most senior centers, health departments, and social service agencies offer meals, rides, and in-home care.

Tony Freeman/PhotoEdit

FIGURE 16.18 Easy meals
Selecting acceptable foods that are nutritious and easy to prepare is important in meeting the needs of the elderly.

Overcoming Medical Limitations Medical conditions and the use of medications often affect food choices. Meals need to be appealing and easy to prepare and consume, as well as compatible with medical conditions. For instance, an individual with dental problems may not be able to chew fresh fruits and vegetables. Therefore, texture modification is required. Fully cooked, canned, or soft fruit or fruit juices can be substituted for hard-to-chew fruits, and cooked vegetables can replace raw ones. Eggs, beans, and stewed meats can provide easy-to-chew protein sources. To overcome changes in the sense of taste and smell, spicy or acidic foods may be limited or emphasized, depending on individual tastes.

Special diets are typically prescribed for individuals with medical conditions such as hypertension, heart disease, diabetes, and kidney disease. These diets may contribute to malnutrition if they restrict favorite foods and if individuals prescribed the diet are not given enough information about how to substitute foods that will provide adequate energy, nutrients, and eating pleasure.[18] Education about what foods are appropriate and how to read food labels can help identify products that fit within dietary restrictions.

Medications can also affect the ability and desire to eat. Physicians, pharmacists, and dietitians can provide information about possible effects on food intake. Purchasing all prescription medications from the same pharmacy will ensure that the pharmacist is aware of all medications an individual is taking and can advise of possible interactions. Health-care

TABLE 16.4 DETERMINE: A Checklist of the Warning Signs of Malnutrition

Disease	Any disease, illness, or condition that causes changes in eating can predispose a person to malnutrition. Memory loss and depression can also interfere with nutrition if they affect food intake.
Eating poorly	Eating either too little or too much can lead to poor health.
Tooth loss/mouth pain	Poor health of the mouth, teeth, and gums interferes with the ability to eat.
Economic hardship	Having to, or choosing to, spend less than $25 to $30 per person per week on food interferes with nutrient intake.
Reduced social support	Not having contact with people on a daily basis has a negative effect on morale, well-being, and eating.
Multiple medicines	The more medicines a person takes, the greater the chances of side effects such as weakness, drowsiness, diarrhea, changes in taste and appetite, nausea, and constipation.
Involuntary weight loss/gain	Unintentionally losing or gaining weight is a warning sign that should not be ignored. Being overweight or underweight also increases the risk of malnutrition.
Needs assistance in self-care	Difficulty walking, shopping, and cooking increases the risk of malnutrition.
Elder above age 80	The risks of frailty and health problems increase with increasing age.

CRITICAL THINKING

Averting Malnutrition

iStockphoto

Shirley is a sedentary 70-year-old woman who lives alone. She has periodontal disease, which has caused her to lose teeth, so she eats foods that are easy to chew, as well as easy to prepare and easy to carry home on the bus.

Shirley's Diet

FOOD	AMOUNT
Breakfast	
Bran flakes	1 cup
Reduced-fat milk	1 cup
Coffee	1 cup
Reduced-fat milk	1 T
Sugar	2 tsp
Lunch	
Chicken noodle soup	1 cup
Saltine crackers	6 crackers
Applesauce	1/2 cup
Dinner	
Reduced-fat milk	1 cup
Instant white rice	1 cup
Ground beef in gravy	3 oz
Peas	1 cup

Compare Shirley's intake to the MyPlate Daily Food Plan in Figure 16.13 for a 70-year-old woman. How many servings from each food group does Shirley need to add?

CRITICAL THINKING QUESTIONS

- **Which of the warning signs of malnutrition in the DETERMINE checklist (see table 16.4) apply to Shirley?**
- **Suggest some easy-to-chew foods she can add to her diet to meet her MyPlate recommendations. How many kcalories will your suggestions add?**
- **If she is maintaining her weight on her current diet, how much weight will she gain in a month if she follows your suggestions daily?**

iProfile Use iProfile to find snacks that are nutrient dense and easy to chew.

providers also need to be informed about all nonprescription medications and vitamin, mineral, or other dietary supplements used and whether or not medications are taken according to the prescription instructions.

Nutrition Programs for the Elderly

To address concerns over the nutritional health of the elderly, the federal Nutrition Screening Initiative was developed to promote screening for and intervention in nutrition-related problems in older adults. This program is working to increase the awareness of nutritional problems in the elderly by involving practitioners and community organizations as well as relatives, friends, and others caring for the elderly in evaluating the nutritional status of the aging population. This program developed the DETERMINE checklist (Table 16.4); the name is based on an acronym for the physiological, medical, and socioeconomic situations that increase the risk of malnutrition among the elderly. The elderly themselves, family members, and caregivers can use this tool to identify when malnutrition is a potential problem (see **Critical Thinking: Averting Malnutrition**).

TABLE 16.5 National Programs Promoting Better Nutrition among Older Americans

Older Americans Act—Title IIIC Congregate and Home-Delivered Nutrition Programs Serves at least one meal five days a week to persons 60 years and older. Meals are served at home or in churches, schools, senior centers, or other facilities.
Older Americans Act—Title VI Congregate and Home-Delivered Nutrition Programs Provides home-delivered and congregate meals to Native American organizations.
Older Americans Act—Title IIID Health Promotion and Disease Prevention Program Provides health promotion and disease prevention services in areas where there are large numbers of economically needy older adults.
Nutrition Screening Initiative Promotes nutritional screening and more attention to nutrition in all health-care and social service settings that provide for older adults.
Supplemental Nutrition Assistance Program (SNAP) Provides coupons or debit cards to low-income individuals including the elderly. These can be used instead of cash to purchase food.
Nutrition Program for the Elderly Provides grants, cash, and commodity foods to states and tribes to supplement congregate and home-delivered meal programs.
Commodity Supplemental Food Program—Elderly Provides food, nutrition education, and health service referrals to individuals with low incomes, including the elderly.
Child and Adult Care Food Program (Adult Day Care) Provides cash reimbursements and food commodities to community day care centers that serve meals and snacks to children and elderly with special needs.
Food Distribution Program on Indian Reservations Distributes commodity foods to low-income persons, including the elderly, living on or near Indian reservations.

To help meet the nutrient needs of older adults, the federal Older Americans Act provides nutrition services to older individuals who are in economic need.[72] Programs that provide nutritious meals in communal settings promote social interaction and can improve nutrient intake. The Elderly Nutrition Programs established by the Older Americans Act provide congregate meals at locations such as senior centers, community centers, schools, and churches. For those who are unable to attend congregate meals, home-delivered meals are available. Older adults who participate in the Elderly Nutrition Programs have been shown to have better nutrient intakes, increased consumption of fruits and vegetables, or improved nutritional status.[36] These and other programs addressing the nutritional needs of older adults are described in Table 16.5.

OUTCOME

Cheng and his wife work hard to maintain a healthy diet and lifestyle. They were shocked, then, to find that the fruits, vegetables, and whole grains in their diet were not providing all of the nutrients Cheng needs. Because of Cheng's low-meat, low-dairy diet, he was consuming little vitamin B_{12}. In addition, he had developed a condition common in older adults called *atrophic gastritis* that reduces the amount of stomach acid. Stomach acid is essential for releasing vitamin B_{12} from the proteins it is bound to in food and allowing it to be absorbed. Without sufficient vitamin B_{12}, the myelin coating on nerves cannot be maintained, and nerve function is disrupted. The vitamin B_{12} injections Cheng's doctor gave him helped to immediately boost his vitamin B_{12} status. To ensure he continued to get enough vitamin B_{12}, he started taking a supplement containing vitamin B_{12}. The vitamin B_{12} in supplements is not bound to proteins, so it is more easily absorbed when stomach acid is low. Cheng is now back to his old self. He continues his healthy diet and lifestyle and takes his supplement. **He is grateful he discovered his condition early, because an untreated vitamin B_{12} deficiency might have resulted in permanent neurological damage.**

SUMMARY

16.1 What Is Aging?

- Aging is the accumulation of changes over time that results in an ever-increasing susceptibility to disease and death. The longest an organism can live, or life span, is a characteristic of a species. The average age to which people in a population live, or life expectancy, is a characteristic of a population.
- As a population, we are living longer but not necessarily healthier lives. The elderly are the fastest-growing segment of the U.S. population. Compression of morbidity, that is, increasing the number of healthy years, is an important public health goal. A healthy diet and lifestyle cannot stop aging but can postpone the onset of many of the physiological changes and diseases that are common in older adults.

16.2 What Causes Aging?

- As organisms become older, the number of cells they contain decreases and the function of the remaining cells declines. This reduces reserve capacity, lowering the organism's ability to maintain homeostasis and increasing the risk of disease.
- The loss of cells and cell function that causes aging is believed to be due to both genetic factors that limit cell life and the accumulation of cellular damage over time.
- How long we live and how long we remain healthy is determined by a combination of genetic, environmental, and lifestyle factors.

16.3 Aging and the Risk of Malnutrition

- The risk of malnutrition increases with age due to the physiological changes that accompany aging. There are changes in the sense of smell that affect the appeal of food, changes in vision that affect the ability to prepare food, changes in digestion and absorption that decrease the intake and absorption of nutrients, changes in metabolism that affect nutrient utilization, changes in weight and body composition that increase health risks and reduce independence, changes in hormonal patterns that affect body function, and changes in immune function that increase the risk of infectious and chronic disease.
- Both infectious and chronic diseases affect nutrient requirements and the ability to consume a nutritious diet. Aging increases the incidence of diseases that reduce mobility and cognitive function, limiting the ability to acquire, prepare, and consume food. The medications used to treat disease also affect nutrition, especially when the medications are taken over long periods of time and when multiple medications are taken simultaneously.
- Low income levels increase the risk of malnutrition among the elderly by limiting the ability to purchase food. Loss of independence contributes to depression, which makes meals less appetizing and decreases the quantity and quality of foods consumed.

16.4 Nutritional Needs and Concerns of Older Adults

- Energy needs are lower in older than in younger adults due to decreases in physical activity, basal metabolic rate, and the thermic effect of food, but the needs for most nutrients remain the same or increase.
- Protein needs are increased by the changes that typically occur with age, so a diet that has plentiful amounts of lean sources of protein is recommended.
- Intakes of fiber and water are often lower than recommended, increasing the risk of dehydration and constipation.
- Low intakes, reduced absorption, and changes in the metabolism of certain micronutrients including vitamin B_{12}, vitamin D, and calcium put older adults at risk of deficiency. Iron requirements decrease in women after menopause, but many older adults are at risk of iron deficiency due to blood loss from disease or medications.

16.5 Keeping Older Adults Healthy

- A healthy diet and regular exercise can prevent malnutrition, delay the onset of chronic conditions, and increase independence in older adults. MyPlate can be used to determine the amounts of food from each food group needed by adults of all ages. Meals for the elderly must be nutrient dense, provide plenty of fluid and fiber, and consider individual medical, psychological, social, and economic circumstances. Supplements of calcium, vitamin D, and vitamin B_{12} may be beneficial. In some cases, assistance with shopping and meal preparation may be needed.
- Underweight and obesity increase health risks in the elderly. Weight management in older adults must focus on diet and exercise to maintain lean body mass.
- A physical activity program for older adults should include activities that improve endurance, strength, flexibility, and balance. Activities should be tailored to the individual's needs and likes. Exercise classes are advantageous for older adults because they provide both social interaction and professional support and instruction. A well-planned exercise program can reduce the risk of chronic disease, improve mobility, increase independence, and reduce the risk of falls and injuries.
- The DETERMINE checklist helps identify older adults who are at risk for malnutrition.
- The federal Older Americans Act includes programs that provide older adults with low-cost or free meals in their homes or in a social setting. Participation in these programs has been found to improve nutrient intake or nutritional status.

CHAPTER OUTLINE

17.1 How Can Food Make Us Sick?
- What Is Food-Borne Illness?
- How Does Food Get Contaminated?
- When Do Contaminants Make Us Sick?

17.2 Keeping Food Safe
- What Is the Government's Role?
- What Is the Role of Food Manufacturers and Retailers?
- What Is the Consumer's Role?

17.3 Pathogens in Food
- Bacteria
- Viruses
- Molds
- Parasites
- Prions

17.4 How to Reduce the Risk of Microbial Food-Borne Illness
- Store Food Properly
- Handle Food Safely
- Cook Food Thoroughly
- Food Safety Away from Home

17.5 Agricultural and Industrial Chemicals in Food
- Risks and Benefits of Pesticides
- Antibiotics and Hormones in Food
- Contamination from Industrial Wastes
- How to Choose Wisely to Minimize Agricultural and Industrial Contaminants

17.6 Technology for Keeping Food Safe
- How Temperature Keeps Food Safe
- How Irradiation Preserves and Protects Food
- How Packaging Protects Food
- Food Additives

(©iStockphoto)

© GMVozd/iStockphoto

Food Safety

17

CASE STUDY

One hundred children at Loghill Elementary School were absent or went home sick on Friday. Forty of them vomited at school. It might have been the stomach flu, but only a few of the teachers and parents became ill, even though they were in contact with the children and presumably would have been just as likely as the children to catch the flu. When this many people in one place become ill at the same time, food-borne illness is always suspected.

Even though almost everyone had recovered by Monday, the local health department was notified. Inspectors came to the school to investigate the cause of the illnesses and were able to trace the source to the "Welcome Back, Spring" celebration held the day before the illness struck. For this event, the first graders made cupcakes, the second graders made cookies, the third graders made fruit salad, and the fourth graders made frozen custard. After interviewing the children and adults who were sick, the inspectors determined that only those who ate frozen custard became ill, and that they all began having symptoms within 48 hours of consuming it. Symptoms included nausea and vomiting, diarrhea, abdominal pain, and fever. Many of the sick children were seen by physicians, and the organism *Salmonella enteritidis* was isolated from their stool samples. **Further investigation revealed that the recipe the fourth graders used to make the frozen custard included six Grade A raw eggs.**

Masterfile

17.1 How Can Food Make Us Sick?

LEARNING OBJECTIVES

- Name the primary cause of food-borne illness in the United States.
- Discuss how and where food can get contaminated.
- Explain why a contaminated food does not cause illness in everyone who eats it.

The American food supply is very safe but it is not risk-free. *Salmonella* bacteria contaminate chickens sold in the United States, industrial waste has polluted some of our waterways, and pesticide residues are found on our fruit. Headlines announce *Listeria* in cantaloupe; *Escherichia coli* (*E. coli*) in meat and apple juice; *Salmonella* in eggs, on vegetables, and in cereal; *Cyclospora* on fruit; *Cryptosporidium* in drinking water; and hepatitis A in frozen strawberries. The Centers for Disease Control and Prevention (CDC) estimates that each year about one in six Americans, or 48 million people, get sick, 128,000 are hospitalized, and 3000 die from food-borne diseases.[1]

If given a choice, most people would elect to consume food that contains no harmful substances. However, choosing a diet that is free of all potential hazards is nearly impossible. Food has always carried the risks of bacterial contamination and naturally occurring toxins. Today, modern agricultural technology, trade patterns, food processing, and changes in dietary habits have increased the risks associated with bacterial contamination and introduced new risks. Regulatory agencies, food manufacturers and retailers, as well as consumers, must work together to maximize the safety of the food supply.

What Is Food-Borne Illness?

food-borne illness An illness caused by consumption of contaminated food.

pathogen A biological agent that causes disease.

toxin A substance that can cause harm at some level of exposure.

Food-borne illness, in the broadest sense, is any illness that is related to the consumption of food or of contaminants or toxins in food. Most of the food-borne illness in the United States is caused by food that is contaminated with **pathogens**, that is, microorganisms or microbes that can cause disease. **Toxins** produced by these microorganisms, as well as chemical and physical contaminants from the environment and those used in the processing and packaging of food, can also cause food-borne illness. Chemical contaminants include substances such as drugs used in raising cattle and producing milk, pesticides and fertilizers used in growing crops, and wastes from industry that accumulate in the environment. Physical contaminants include substances as diverse as broken glass and insect wings. Even substances we use to protect the food supply, such as packaging materials and preservatives, have the potential to cause harm if not properly used.

How Does Food Get Contaminated?

Food can be contaminated at any point in its journey from production to when it is prepared in your kitchen (Figure 17.1). Often, food is contaminated where it is grown or produced. *E. coli* from improperly treated manure fertilizer can contaminate strawberries in the field. *Salmonella enteritidis* may enter eggs directly from hens infected with the bacteria. Fish and seafood may be contaminated by agricultural runoff, sewage, and other toxins in the waters where they live. Molds may grow on grains during unusually wet or dry growing seasons. Food can also be contaminated during processing or storage, at retail facilities, during transport, and even at home. This often occurs by **cross-contamination** from a contaminated food or piece of equipment to an uninfected one. For example, *E. coli* from a single cow can contaminate processing equipment and be transferred to thousands of pounds of hamburger. Careful sanitation and handling procedures can control most of these sources of food-borne illness.

cross-contamination The transfer of contaminants from one food or object to another.

When Do Contaminants Make Us Sick?

Even when a food is contaminated, it does not cause every individual who consumes it to become ill. The potential of a substance to cause harm depends on how potent it is, the amount or dose that is consumed, how frequently it is consumed, and who consumes it. Some food contaminants cause harm even when minute amounts are consumed, and almost any substance can be toxic if a large

Masterfile

1 Farm
Crops can be contaminated with bacteria before they are even harvested.

5 Table
Even a safe food can be contaminated in the home if it is not handled, stored, and prepared safely.

Thinkstock Images/Getty Images, Inc.

Masterfile

2 Processing
Cross-contamination from food or equipment can transfer microbes to large volumes of food.

David Freund/iStockphoto

Digital Vision/Getty Images, Inc.

3 Transportation
During transport, poor sanitation and inadequate refrigeration can contaminate food and allow microbes to grow.

4 Retail
Food can become contaminated during handling or storage in grocery stores or during preparation in restaurants.

FIGURE 17.1 Sources of food contamination
Keeping food safe involves identifying possible points of contamination along its journey from the farm to the dinner table.

THINK CRITICALLY

Why does contamination that occurs during processing have the potential to make more people sick than contamination that occurs at home?

enough amount is consumed. Many substances have a **threshold effect**; that is, they are harmless up to a certain dose or threshold, after which negative effects increase with increasing intake.

How well a substance is absorbed and how it is metabolized by the body affect toxicity. Dietary factors and nutritional status can affect absorption. For example, mercury, which is extremely toxic, is not absorbed well if the diet is high in selenium, and lead absorption is decreased by the presence of iron and calcium in the diet. Contaminants that are stored in the body after being absorbed are more likely to be toxic because they accumulate over time, eventually causing symptoms of toxicity. Contaminants that are easily excreted from the body are less likely to cause toxicity.

An individual's size, overall health and nutritional status, and immune function affect his or her risk of food-borne illness. Infants and children are at greater risk than adults because their immune systems are immature and their small size means that a given amount of contaminant represents a greater amount per unit of body weight than it would in an adult. Elderly people, people with AIDS, and those receiving chemotherapy or other immunosuppressant drugs are at increased risk because their immune systems may be compromised. Pregnancy weakens the immune system, putting pregnant women and their unborn babies at risk. Poor nutritional status and chronic conditions such as diabetes and kidney disease may decrease the body's ability to detoxify harmful substances.

threshold effect A reaction that occurs at a certain level of ingestion and increases as the dose increases. Below that level there is no reaction.

LIFE CYCLE

17.2 Keeping Food Safe

LEARNING OBJECTIVES

- Explain how a HACCP system helps prevent food-borne illness.
- Discuss the roles of the federal agencies responsible for the safety of the U.S. food supply.
- Discuss the role of the consumer in keeping food safe.

Ensuring the safety of the food supply is a responsibility shared by the government, food manufacturers and retail establishments, and consumers. The steps taken to avoid food-borne illness require weighing the benefits a food provides against the potential risks it presents. This type of risk–benefit analysis is done by regulatory agencies when they evaluate the safety and sanitation of food-processing methods and food service establishments. Not every potential contaminant is harmful, nor can all be avoided, but those that have a great potential for harm need to be addressed. Consumers should also consider the risks and benefits when they choose which foods to buy, which to eat, and how to handle, store, and cook these foods.

What Is the Government's Role?

Agencies at the international, federal, state, and local levels monitor the safety of the food supply (Table 17.1). Federal agencies set standards and establish regulations for the safe and sanitary handling of food and water and for the information on food labels. They regulate the use

TABLE 17.1 Agencies That Monitor the Food Supply

International Organizations	
Food and Agriculture Organization of the United Nations (FAO)	Promotes and shares knowledge in all aspects of food quality and safety and in all stages of food production: harvest, post-harvest handling, storage, transport, processing, and distribution.
World Health Organization (WHO)	Develops international food safety policies, food inspection programs, and standards for hygienic food preparation; promotes technologies that improve food safety and consumer education about safe food practices. Works closely with the FAO.
Federal Organizations	
U.S. Food and Drug Administration (FDA)	Ensures the safety and quality of all foods sold across state lines with the exception of red meat, poultry, and egg products; inspects food processing plants; inspects imported foods with the exception of red meat, poultry, and egg products; sets standards for food composition; oversees use of drugs and feed in food-producing animals; enforces regulations for food labeling, food and color additives, and food sanitation.
U.S. Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS)	Enforces standards for the wholesomeness and quality of red meat, poultry, and egg products produced in the United States and imported from other countries. If an imported food is suspect, it can be tested for contamination and denied entry into the country.
U.S. Environmental Protection Agency (EPA)	Regulates pesticide levels and must approve all pesticides before they can be sold in the United States; establishes water quality standards.
National Marine Fisheries Service	Oversees the management of fisheries and fish harvesting; operates a voluntary program of inspection and grading of fish products.
National Oceanic and Atmospheric Administration (NOAA)	Oversees fish and seafood products. Its Seafood Inspection Program inspects and certifies fishing vessels, seafood processing plants, and retail facilities for compliance with federal sanitation standards.
Centers for Disease Control and Prevention (CDC)	Monitors and investigates the incidence and causes of food-borne illnesses.
State and Local Governments	
Oversee all food within their jurisdiction; also inspect restaurants, grocery stores, and other retail food establishments, as well as dairy farms and milk processing plants, grain mills, and food manufacturing plants within local jurisdictions.	

of agricultural chemicals, additives, and packaging materials; inspect food-processing and storage facilities; monitor both domestic and imported foods for contamination; and investigate outbreaks of food-borne illness. State agencies have the primary responsibility for milk safety and the inspection of restaurants, retail food stores, dairies, grain mills, and other food-related establishments within their borders. As a result, regulations vary from state to state. To provide guidance, the U.S. Food and Drug Administration (FDA) publishes the **Food Code**, which offers recommendations for safeguarding public health when food is served to the consumer.[2]

Food Code A set of recommendations published by the FDA for the handling and service of food sold in restaurants and other establishments that serve food.

Concern about the prevalence of food-borne illness led to the establishment of the National Food Safety Initiative in 1997. The goal of this initiative is to reduce the incidence of food-borne illness by improving food safety practices and policies throughout the United States. The focus is on reducing the risk of microbial food-borne illness.[3] In 2011, in response to the continued threat from our food supply, the FDA Food Safety Modernization Act was passed. This legislation focuses on preventing food-borne illness, not just reacting to problems as they occur. It gave the FDA an inspection mandate and new legal powers to ensure that companies are doing their part to stop potentially unsafe food from entering the marketplace.[4]

Identifying Potential Problems In the past, food safety was monitored by conducting spot-checks of manufacturing conditions and products. These checks often relied on visual inspection to detect contamination and typically did not find a problem until after it had already occurred. The current system for safeguarding the food supply is called **Hazard Analysis Critical Control Point (HACCP)**. This is a science-based approach designed to prevent food contamination rather than catch it after it occurs.

Hazard Analysis Critical Control Point (HACCP) A food safety system that focuses on identifying, preventing, and eliminating hazards that could cause food-borne illness.

The HACCP approach to food safety involves establishing standardized procedures to prevent, control, or eliminate contamination before food reaches consumers (Table 17.2). It

TABLE 17.2 Seven Principles of HACCP

1. Conduct a hazard analysis.	Analyze the processes associated with the production of a food to identify the potential biological, chemical, and physical hazards and determine what type of preventive measures, such as changes in temperature, pH, or moisture level, could be used to control or avoid these hazards.
2. Identify critical control points.	Identify steps in a food's production, called *critical control points*, at which the potential hazard can be prevented, controlled, or eliminated—for example, cooking, cooling, packaging, and metal detection.
3. Set critical limits.	Establish preventive procedures with measurable limits for all critical control points. For example, for a cooked food this might be a minimum cooking time and temperature required to ensure elimination of harmful microbes. If these critical limits are not met, the food safety hazards are not being prevented, eliminated, or reduced to acceptable levels.
4. Monitor the critical control points.	Develop procedures to monitor the critical limits. For example, how and by whom will the cooking temperature be monitored? Adjustments can be made while continuing the process.
5. Establish corrective actions.	Establish plans to discard the potentially hazardous product and to correct the out-of-control process when monitoring shows that a critical limit has not been met—for example, reprocessing or discarding food if the minimum cooking temperature is not met.
6. Maintain record-keeping and documentation procedures.	Prepare and maintain a written HACCP plan. This would include records of hazards and their control methods, the monitoring of each critical control point, and notations of corrective actions taken. Each principle must be backed by sound scientific knowledge—for example, published studies on the time and temperatures needed to control specific food-borne pathogens.
7. Institute verification procedures.	Institute procedures to verify the scientific or technical validity of the hazard analysis, the adequacy of the critical control points, and the effectiveness of the HACCP plan. An example of verification is the testing of time and temperature recording devices to verify that a cooking unit is working properly.

Source: U.S. Food and Drug Administration.

critical control points Possible points in the food production, manufacturing, and transportation processes at which controls can be applied and contamination prevented or eliminated.

focuses on identifying points in the handling of food, called **critical control points**, where chemical, physical, or microbial contamination can be prevented, controlled, or eliminated. The HACCP system requires the food manufacturing and food service industries to anticipate where contamination might occur. It also establishes record-keeping procedures to verify that the system is working consistently. The advantages of the HACCP system over standard inspections by the FDA are that it is preventive rather than punitive, it is easier to manage, and it puts the responsibility for food safety on the manufacturer, not the regulatory agencies.

Tracking Food-Borne Illness The Foodborne Diseases Active Surveillance Network, also known as FoodNet, monitors and tracks food-borne illness in order to estimate the number of cases, identify specific foods and settings that are involved, monitor trends over time, and disseminate this information.[5] The National Molecular Subtyping Network for Foodborne Disease Surveillance, or PulseNet, helps identify the source of an outbreak of food-borne illness by tracking the distinctive "DNA fingerprint" of a pathogenic strain of microorganism. These organizations work together to identify the source of food contaminants and stop the progression of outbreaks. For example, if outbreaks of food-borne illness in Ohio and Minnesota were found to be caused by the same strain of an organism, epidemiologists know that they were caused by the same food source. Trackers can then focus their search for the source of contamination on foods distributed to both locations.

What Is the Role of Food Manufacturers and Retailers?

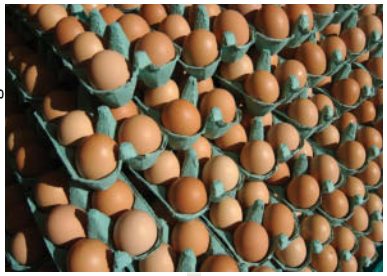
The responsibility of providing safe food to the marketplace falls on the shoulders of food manufacturers. It is their job to establish and implement a HACCP system for their particular business. Once in place, it allows the company to anticipate where contamination might occur and then to prevent hazardous food from reaching the consumer. Figure 17.2 provides an example of how a HACCP system is used to ensure the safety of liquid egg products. To produce these products, eggs are removed from their shells; mixed together in large vats; heated, in a process called **pasteurization**, to kill *Salmonella* and other microbial contaminants; packaged; and then refrigerated or frozen.

pasteurization The process of heating food products to kill disease-causing organisms.

Food manufacturers are also responsible for proper labeling of their products. In addition to nutritional labeling, some products also contain safe-handling labels as well as some type of product dating. A "use by" date, also called a "best if used by," "freshness," or "quality assurance" date, refers to the last date the product is likely to be at peak flavor, freshness, and texture. Beyond this date, the product's quality may diminish, but the food may still be safe if it has been handled and stored properly. A "sell-by" or "pull-by" date indicates when the grocery store should take the product off the shelf. You should buy the product before the date, but if the food has been handled and stored properly, it is usually still safe for consumption after it. For example, milk usually can be used for up to about seven days after the sell-by date. Some foods also have an "expiration date." This is used to specify the last date that the food should be eaten. State governments regulate these dates for perishable items such as milk and eggs. The FDA regulates only the expiration dates of infant formulas.

Once food has left the manufacturer, it goes to restaurants and other retail establishments. These businesses are responsible for preventing contaminated food from reaching the consumer. They must monitor the food that enters the establishment and prevent infected food, utensils, and employees from cross-contaminating food served to customers. Food in retail establishments has many opportunities to be contaminated because of the large volume of food that is handled and the large number of people involved in food preparation. Although much of the food-borne illness in the United States is caused by food prepared in private homes, an outbreak in a commercial or institutional establishment usually involves more people at a time and is more likely to be reported.

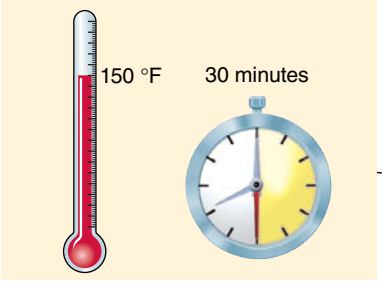
Even when a restaurant uses extreme care in food preparation, customers can be a source of contamination. Because customers serve themselves at salad bars, cross-contamination from coughs



Keen Press/NG Image Collection

1 Conduct a hazard analysis.
The manufacturer analyzes its processing steps for potential hazards and determines preventive measures that can be taken. Contamination of eggs with the bacterium *Salmonella* is a potential hazard. Adequate heating is a preventive measure that can eliminate this hazard.

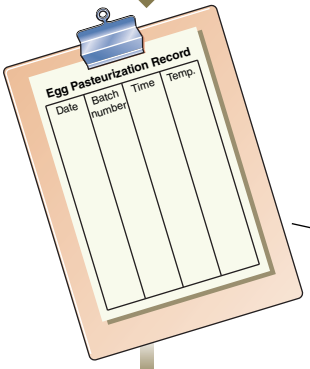
2 Identify the critical control points.
The critical control point in egg processing is pasteurization of the shelled egg mixture.



3 Set critical limits.
The critical limits for egg pasteurization are sufficient heating time and temperature to ensure that *Salmonella* bacteria are killed.

Hank Morgan/Photo Researchers, Inc.

4 Monitor the critical control points.
Each batch of pasteurized eggs is tested for *Salmonella.* If the temperature is not high enough or the heating is not continued long enough, *Salmonella* can survive, as shown here by the growing bacterial colonies.



5 Establish corrective action.
Batches of eggs that are contaminated with *Salmonella* are discarded and the temperature of the heat chamber is adjusted to ensure that *Salmonella* in the next batch will be killed.

6 Maintain record-keeping procedures.
Extensive records are kept, documenting the monitoring of critical control points and corrective actions taken. This enables the source of a problem to be traced in the event of an outbreak of food-borne illness.

Dorling Kindersley/Getty Images, Inc.

7 Institute verification procedures.
Plans and records are continually reviewed to ensure that the HACCP plan is working and only safe eggs are reaching consumers.

FIGURE 17.2 HACCP in liquid egg production
The scrambled eggs served in your cafeteria at school or work most likely came out of a carton rather than a shell. This example shows how a HACCP system might be used to prevent contaminated liquid egg products from reaching consumers.

Catherine Karnow/© Corbis

FIGURE 17.3 Sneeze guards protect food
Clear plastic shields placed above salad bars and buffets prevent customers from contaminating food with microorganisms transmitted by coughs and sneezes.

and sneezes as well as shared serving utensils is a risk. To limit this, salad and dessert bars in restaurants are usually equipped with "sneeze guards" (Figure 17.3).

What Is the Consumer's Role?

Consumers should be actively involved in preventing food-borne illness. Individuals must decide what foods they will consume and evaluate the risks involved. A food that has been manufactured, packaged, and transported with the greatest care can still cause food-borne illness if it is not carefully handled at home. For example, contaminated eggs, chicken, and hamburger can cause microbial food-borne illness if they are not thoroughly cooked. Just as manufacturers are asked to identify critical control points in food handling where contamination can be prevented, eliminated, and monitored, consumers can take a similar approach in selecting, storing, preparing, and serving food and leftovers. Consumers can also protect themselves and others by reporting incidents involving unsanitary, unsafe, deceptive, or mislabeled food to the appropriate agencies (Table 17.3).

TABLE 17.3 How to Report Food-Related Issues

Before reporting a suspected case of food contamination, get all the facts. Determine whether you have used the product as intended and according to the manufacturer's instruction. Check to see if the item is past its expiration date. After these steps have been taken, report the incident to the appropriate agency:
• **Problems related to any food except meat and poultry, including adverse reactions:** Report emergencies to the FDA's main emergency numbers, which are staffed 24 hours a day: 866-300-4374 or 301-796-8240. Nonemergencies can be reported to the FDA Consumer Complaint Coordinator in your area, which you can find at www.fda.gov/safety/reportaproblem.
• **Issues related to meat and poultry:** Report first to your state department of agriculture and then to the USDA Meat and Poultry Hotline (1–888-MPHotline or mphotline.fsis@usda.gov).
• **Restaurant food and sanitation problems:** Report directly to your local or state health department.
• **Issues related to alcoholic beverages:** Report to the U.S. Department of the Treasury's Bureau of Alcohol, Tobacco, Firearms and Explosives.
• **Pesticide, air, and water pollution:** Report first to your state environmental protection department and then to the U.S. EPA.
• **Products purchased at the grocery store:** Return to the store. Grocery stores are concerned with the safety of the foods they sell, and they will take responsibility for tracking down and correcting the problem. They will either refund your money or replace the product.

17.3 Pathogens in Food

LEARNING OBJECTIVES

- Distinguish food-borne infection from food-borne intoxication.
- Discuss three types of bacteria that commonly cause food-borne illness.
- Explain how viruses, molds, parasites, and prions can make us sick.

food-borne infection
Illness produced by the ingestion of food containing microorganisms that can multiply inside the body and cause injurious effects.

food-borne intoxication
Illness caused by consuming a food containing a toxin.

The pathogens that most commonly affect the food supply include bacteria, viruses, molds, and parasites (Table 17.4).[6] An illness caused by consuming food contaminated with pathogens that multiply in the gastrointestinal tract or other parts of the body is called a **food-borne infection**. An illness caused by consuming food containing toxins produced by a pathogen is referred to as a **food-borne intoxication**. Unlike food-borne infections, which are usually caused by ingesting large numbers of pathogens, intoxication can be caused by only a few microorganisms that have produced a toxin. These toxins may be difficult to destroy.

TABLE 17.4 Summary of Bacterial, Viral, and Parasitic Food-Borne Illnesses[6]

Microbe	Sources	Symptoms	Onset (time after consumption)	Duration
Bacteria				
Campylobacter jejuni	Unpasteurized milk, untreated water, undercooked meat and poultry	Fever, headache, diarrhea, abdominal pain	2–5 days	2–10 days
Clostridium botulinum	Improperly canned foods, deep-dish casseroles, honey	Lassitude, weakness, vertigo, respiratory failure, paralysis	18–36 hours	10 days or longer (must administer antitoxin)
Clostridium perfringens	Fecal contamination, deep-dish casseroles	Nausea, diarrhea, abdominal pain	About 16 hours	12–24 hours
Escherichia coli O157:H7	Fecal contamination, undercooked ground beef	Abdominal pain, bloody diarrhea, kidney failure	1–9 days	2–9 days in uncomplicated cases
Listeria monocytogenes	Raw milk products; soft ripened cheeses; deli meats and cold cuts, raw and undercooked poultry; meats; raw and smoked fish; raw vegetables	Fever, headache, stiff neck, chills, nausea, vomiting. May cause spontaneous abortion or stillbirth in pregnant women and meningitis and blood infections in the fetus.	Hours to weeks	Days to weeks
Salmonella	Fecal contamination, raw or undercooked eggs and meat, especially poultry, contaminated produce	Nausea, abdominal pain, diarrhea, headache, fever	6–72 hours	4–7 days
Shigella	Fecal contamination of water or foods, especially salads such as chicken, tuna, shrimp, and potato salads	Diarrhea, abdominal pain, fever, vomiting	8–50 hours	5–7 days
Staphylococcus aureus	Human contamination from coughs and sneezes; eggs, meat, potato and macaroni salads	Severe nausea, vomiting, diarrhea	1–7 hours	Hours–1 day
Vibrio parahaemolyticus	Raw seafood from contaminated water	Cramps, diarrhea, fever, nausea, vomiting	4–90 hours	2–6 days
Yersinia enterocolitica	Pork, unpasteurized milk, and oysters	Diarrhea, vomiting, fever, abdominal pain; often mistaken for appendicitis	1–11 days	A few days–3 weeks
Viruses				
Hepatitis A	Human fecal contamination of food or water, raw shellfish	Jaundice, liver inflammation, fatigue, fever, nausea, anorexia, abdominal discomfort	15–50 days	1–2 weeks to several months
Norovirus	Fecal contamination of water or foods, especially shellfish and salad ingredients	Diarrhea, nausea, vomiting	24–48 hours	12–60 hours
Parasites				
Anisakis simplex	Raw fish	Severe abdominal pain	24 hours–2 weeks	3 weeks
Cryptosporidium parvum	Fecal contamination of food or water	Severe watery diarrhea	7–10 days	2–14 days, but may become chronic
Giardia lamblia	Fecal contamination of water and uncooked foods	Diarrhea, abdominal pain, gas, anorexia, nausea, vomiting	1–2 weeks	2–6 weeks, but may be chronic
Toxoplasma gondii	Meat, primarily pork	Toxoplasmosis (can cause central nervous system disorders, flu-like symptoms, and birth defects in the offspring of women exposed during pregnancy; see Chapter 11)	5–23 days	Several weeks; may become chronic
Trichinella spiralis	Undercooked pork, game meat	Muscle weakness, flu-like symptoms	1–4 weeks	Several weeks

In most cases, the symptoms of a microbial food-borne illness include abdominal pain, nausea, diarrhea, and vomiting. These symptoms are often mistaken for the flu. Food-borne illness can also cause more severe symptoms such as spontaneous abortion, hemolytic uremic syndrome, arthritis, and Guillain-Barré syndrome. Young children, pregnant women, elderly persons, and individuals with compromised immune systems are most susceptible to severe reactions.

Bacteria

Bacteria are present in the soil, on our skin, on most surfaces in our homes, and in the food we eat. Most of the bacteria in our environment are harmless, some are beneficial, and some are pathogenic, causing food-borne infection or intoxication. Some common causes of bacterial infections include *Salmonella, E. coli*, *Campylobacter jejuni*, *Listeria monocytogenes*, and *Vibrio*. *Staphylococcus aureus, Clostridium perfringens*, and *Clostridium botulinum* cause food-borne intoxication.

B. Anthony Stewart/Getty Images, Inc.

FIGURE 17.4 The spread of *Salmonella*
Salmonella can infect the ovaries of hens and contaminate the eggs before the shells are formed, so that the bacteria are present inside the shell when the eggs are laid. Therefore, eggs should never be eaten raw.

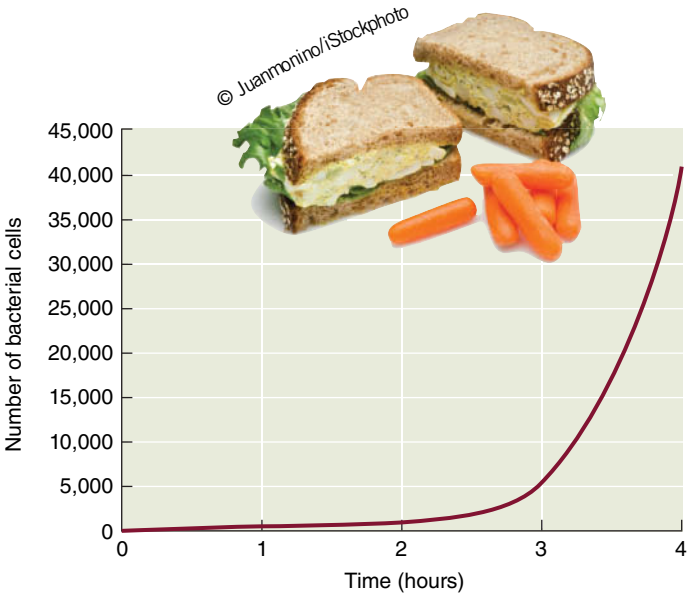


FIGURE 17.5 Exponential bacterial growth
The size of a population of bacterial cells doubles each time the cells divide; thus, if 10 bacterial cells contaminate an egg-salad sandwich during preparation and it sits in your warm car for four hours, during which the cells divide every 20 minutes, there will be 40,960 bacterial cells in the sandwich by the time you eat it.

Salmonella *Salmonella* is the most common cause of bacterial food-borne illness in the United States.[7] Most people who become infected just experience abdominal pain and diarrhea, but in rare cases infections are more serious. *Salmonella* is responsible for more deaths and hospitalizations than other food-borne pathogens.[8] It is found in animal and human feces and infects food through contaminated water or improper handling. Although poultry and eggs are the foods most often contaminated, *Salmonella* has also been found in meats, dairy products, seafood, fresh fruits and vegetables, and processed foods such as frozen pot pies. Poultry products are at high risk for contamination because poultry farms house large numbers of chickens in proximity, allowing one infected chicken to infect thousands of others (Figure 17.4).

Even when food contaminated with *Salmonella* is brought into the kitchen, careful handling and cooking of the food can prevent the organisms from causing illness. Washing hands, cutting boards, and utensils can prevent cross-contamination. If a contaminated food is stored in the refrigerator, the multiplication of the *Salmonella* will be slowed. In contrast, if a contaminated food is left at room temperature, the *Salmonella* will multiply rapidly, and when the food is eaten, large numbers of bacteria will be ingested with it (Figure 17.5). *Salmonella* is killed by heat—so foods likely to be contaminated, such as poultry and eggs, should be cooked thoroughly.

Escherichia coli (E. coli) *E. coli* is a bacterium that inhabits the gastrointestinal tracts of humans and other animals. It comes in contact with food through fecal contamination of water or unsanitary handling of food. Transmission of *E. coli* is also a risk at day-care centers from cross-contamination if caregivers do not carefully wash their hands after diaper changes. Some strains of *E. coli* are harmless, but others can cause serious food-borne illness. One strain of *E. coli*, found in water contaminated by human or animal feces, is the cause of "travelers' diarrhea." Another strain, *E. coli* O157:H7, produces a toxin that causes abdominal pain, bloody diarrhea, and, in severe cases, a form of kidney failure called *hemolytic uremic syndrome*, which can be fatal.

E. coli O157:H7 bacteria live in the intestines of healthy cattle and can contaminate the meat after slaughter. *E. coli* on food can multiply, even at refrigerator temperatures, but if a contaminated food is thoroughly cooked to 160°F, both the bacteria and the toxin are destroyed. Ground beef contaminated with *E. coli* O157:H7 is a particular risk because, unlike solid pieces of meat that are only contaminated on the surface, grinding mixes the bacteria throughout the meat (**Figure 17.6**). The *E. coli* on the outside of the meat are quickly killed during cooking, but those in the interior survive if the meat is not cooked thoroughly.

E. coli O157:H7 entered the public spotlight in 1993, when it caused the deaths of several children who had consumed undercooked, contaminated hamburgers from a fast-food restaurant. Thorough cooking of the hamburgers would have killed the bacteria that caused these deaths. *E. coli* O157:H7 can also contaminate produce. Organic spinach and spring mix was contaminated in 2012, sickening people in five states, and contaminated ready-to-eat salad mix infected 33 people from four different states in 2013.[9,10] Other foods that are typically eaten raw, such as bologna, have also caused *E. coli* O157:H7 infection.[11]A new, even more deadly strain of *E. coli* (*E. coli* O104:H4) emerged in Germany in 2011, ultimately sickening more than 4000 people in 16 countries.[12]

John A. Rizzo/Photodisc/Getty Images, Inc.

FIGURE 17.6 Ground beef and *E. coli* contamination During grinding, the bacteria on the surface of the meat are mixed throughout. *E. coli*–contaminated meat that comes into contact with a grinder contaminates the grinder and may transfer the bacteria to hundreds of pounds of beef that subsequently pass through it.

Campylobacter *Campylobacter jejuni* is the leading cause of acute bacterial diarrhea in the United States, affecting about 845,000 people annually.[7] Common sources are undercooked chicken, unpasteurized milk, cheeses made from unpasteurized milk, and untreated water. A sampling of raw chicken from supermarkets from 2005 to 2011 found that about 40% of samples were contaminated with *Campylobacter*.[13] This organism grows slowly in cold temperatures and is killed by heat, so careful storage and thorough cooking help prevent infection.

Listeria Another cause of bacterial food-borne infection is *Listeria monocytogenes*. Although food-borne *Listeria monocytogenes* sickens fewer people than *Salmonella* or *Campylobacter,* this bacterium is one of the leading causes of death from food-borne illness, with a fatality rate of 21%.[6,14] Almost all *Listeria* infections occur in people in high-risk groups, such as pregnant women, children, elderly people, and people with compromised immune systems. It can cause flu-like symptoms or be more serious if the infection spreads through the bloodstream to the nervous system. Pregnant women are at particular risk; *Listeria* infection is 18 times more common in pregnant women than in the general population. Infection during pregnancy is associated with an increased risk of spontaneous abortion and stillbirth, and it can be transmitted to the fetus, causing meningitis and serious blood infections.[15]*Listeria* is ubiquitous in the environment and can survive and grow at refrigerator temperatures. Because it can grow at cool temperatures, this bacterium can infect ready-to-eat foods such as hot dogs, lunch meats, smoked fish, and cheeses even if they have been kept properly refrigerated. *Listeria* frequently contaminates dairy products, but it is destroyed by pasteurization. To prevent infection, ready-to-eat meats like hot dogs should be heated to steaming and unpasteurized dairy products should be avoided.

Vibrio *Vibrio* bacteria can cause illness when contaminated seafood is eaten. *Vibrio* infection causes gastrointestinal upset but can be deadly in people with compromised immune systems. *Vibrio parahaemolyticus* sickens about 45,000 people per year. Another species, *Vibrio vulnificus*, infects fewer people but is more often fatal.[6] The most common way in which people become infected is by eating raw or undercooked shellfish, particularly oysters. *Vibrio* bacteria grow in warm seawater. The incidence of *Vibrio* infection is higher during the summer months, when warm water favors growth.

Staphylococcus aureus *Staphylococcus aureus* is a common cause of microbial food-borne intoxication. These bacteria live in human nasal passages and can be transferred through coughing

© Olga Demchishina/iStockphoto

FIGURE 17.7 Honey may contain botulinum spores
After 1 year of age, the gut microbiota has matured enough to prevent *Clostridium botulinum* spores from germinating, so it is safe to include honey in the diet.

or sneezing when handling food. The bacteria then produce toxins as they grow on the food. When ingested, the toxin causes symptoms that include nausea, vomiting, diarrhea, abdominal cramps, and headache. Ham, salads, bakery products, and dairy products are common sources of *Staphylococcus aureus*.

Clostridium perfringens The bacterium *Clostridium perfringens* may cause illness by both infection and intoxication. It is found in soil and in the intestines of animals and humans. It thrives in conditions with little oxygen (anaerobic conditions) and is difficult to kill because it forms heat-resistant **spores**. Spores are a stage of bacterial life that remains dormant until environmental conditions favor growth. *Clostridium perfringens* is often called the "cafeteria germ" because foods stored in large containers, such as those used to serve food in cafeteria lines, have anaerobic centers that provide an excellent growth environment. Sources include improperly prepared roast beef, turkey, pork, chicken, and ground beef.

Clostridium botulinum Another strain of *Clostridium, Clostridium botulinum*, produces the deadliest bacterial food-borne toxin. Although the bacteria themselves are not harmful, the toxin, produced as the bacteria begin to grow and develop, blocks nerve function, resulting in vomiting, abdominal pain, double vision, dizziness, and paralysis causing respiratory failure. If untreated, botulism poisoning is often fatal, but today modern detection methods and rapid administration of antitoxin have reduced mortality. Low-acid foods, such as potatoes or stews that are held in large containers where anaerobic conditions prevail, provide an optimal environment for botulism spores to germinate. Canned foods, particularly improperly home-canned foods, can also be a source of botulism. Canned foods should be discarded if the can is bulging because this indicates the presence of gas produced by bacteria as they grow. Once formed, botulism toxin can be destroyed by boiling, but if the safety of a food is in question, it should be discarded; even a taste of botulism toxin can be deadly.

LIFE CYCLE

Infant botulism, though rare, occurs worldwide and is the most common form of botulism in the United States.[16] It occurs when botulism spores are ingested and germinate in the gastrointestinal tract, producing toxin. Only infants are affected because in adults, the intestinal microbiota prevents spores from germinating. Some of the toxin is absorbed into the infant's bloodstream, causing weakness, paralysis, and respiratory problems. Administration of an infant botulism antitoxin speeds recovery.[17] Botulism spores can contaminate honey, so it should never be fed to children younger than 1 year of age (Figure 17.7).

Viruses

spore A dormant state of some bacteria that is resistant to heat but can germinate and produce a new organism when environmental conditions are favorable.

Unlike bacteria, the viruses that cause human diseases cannot grow and reproduce in foods. Human viruses can reproduce only inside human cells. When food or water contaminated with virus particles is ingested, the virus makes us ill by entering our cells and converting them into virus-making factories (Figure 17.8).

Noroviruses Noroviruses are a group of viruses that cause gastroenteritis, or what we commonly think of as the "stomach flu." Symptoms, which include stomach pain, nausea, vomiting, and diarrhea, typically resolve within one to three days. Noroviruses are now recognized as the most common cause of infectious gastroenteritis among persons of all ages (Figure 17.9). Each year, they cause about 19 to 21 million people to become ill and lead to 56,000 to 71,000 hospitalizations and 570 to 800 deaths.[18] Norovirus illness is contracted either by eating food that is contaminated with the virus or by touching a contaminated surface and then touching the mucous membranes of your mouth, nose, or eyes. Shellfish can be contaminated with norovirus if the water in which they live is polluted with human or animal feces. Cooking destroys noroviruses, so water and uncooked foods such as leafy vegetables, fruits, and nuts are the most common causes of norovirus food-borne illness. Most outbreaks are caused by food contaminated during preparation and service; one study found that infected food handlers may have contributed to 82% of the outbreaks examined.[19] Norovirus infection can be spread from one infected person

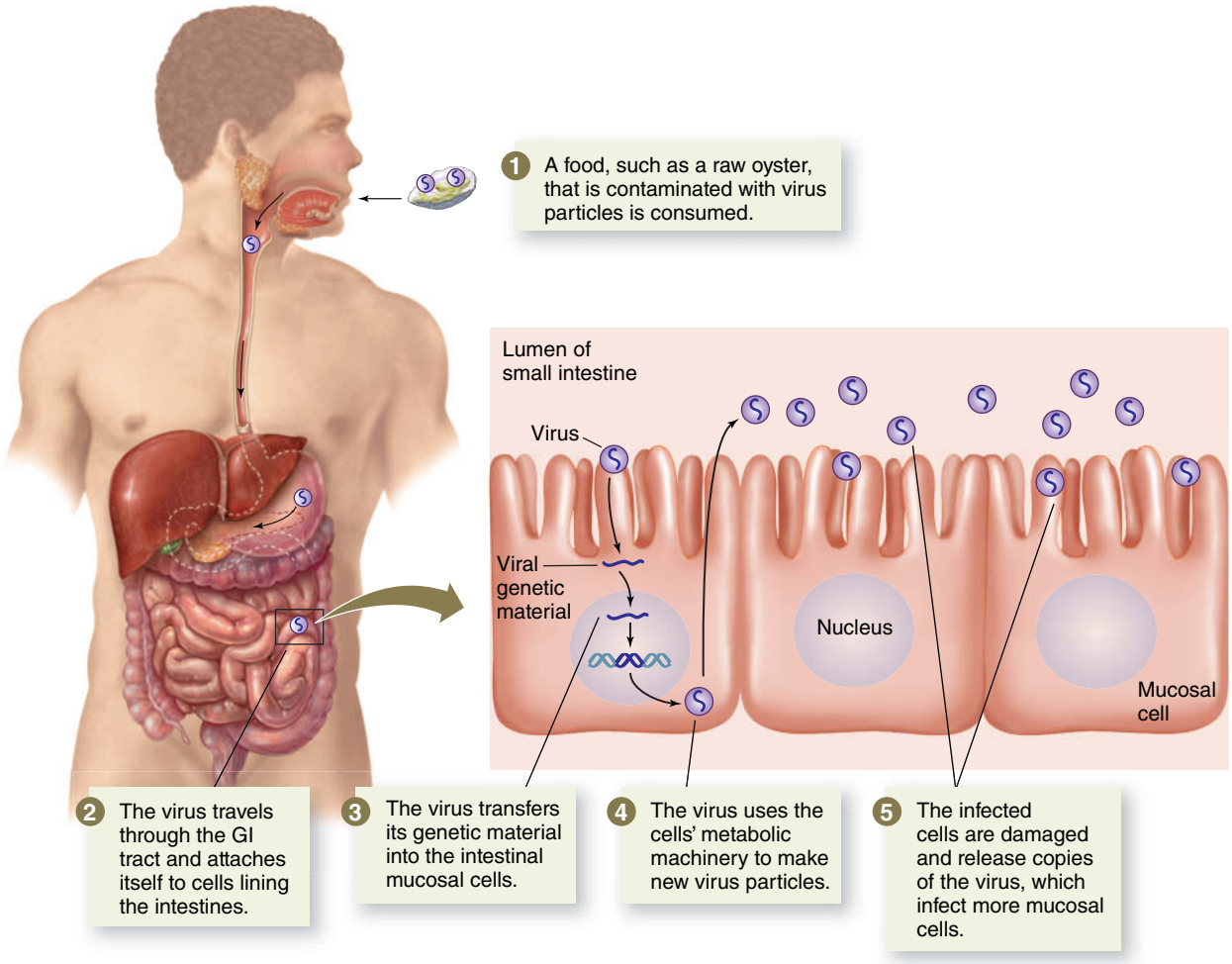


FIGURE 17.8 How viruses make us sick
Viruses make us sick by reproducing inside our cells. Viruses that cause food-borne illness enter the body through the gastrointestinal tract. Other types of viruses may enter the body through open cuts, the respiratory tract, or the genital tract.

to another, so it spreads swiftly where many people congregate in a small area. Epidemics aboard cruise ships often make headlines, but norovirus outbreaks are just as likely to occur in nursing homes, restaurants, hotels, and dormitories as they are aboard cruise ships.

Hepatitis A Hepatitis A is a highly contagious viral disorder that causes inflammation of the liver, jaundice, fever, nausea, fatigue, and abdominal pain. It can be contracted from food or

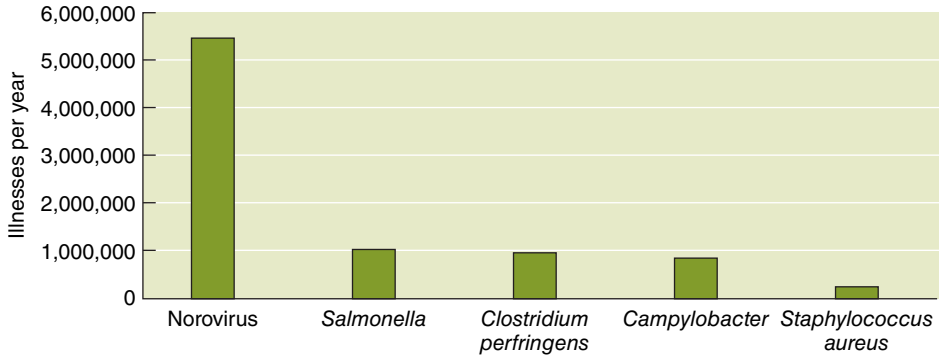


FIGURE 17.9 Causes of food-borne illness
Over half of the domestically acquired food-borne illnesses caused by known pathogens are due to norovirus infections.[1]

THINK CRITICALLY

Why are people on cruise ships at high risk for norovirus infection?

water that has been contaminated with fecal matter. Hepatitis A can require a recovery period of several months, but it usually does not need treatment and does not cause permanent liver damage. Hepatitis in drinking water is destroyed by chlorination. Cooking destroys the virus in food, and good sanitation can prevent its spread. A vaccine that protects against hepatitis A infection is available.

Molds

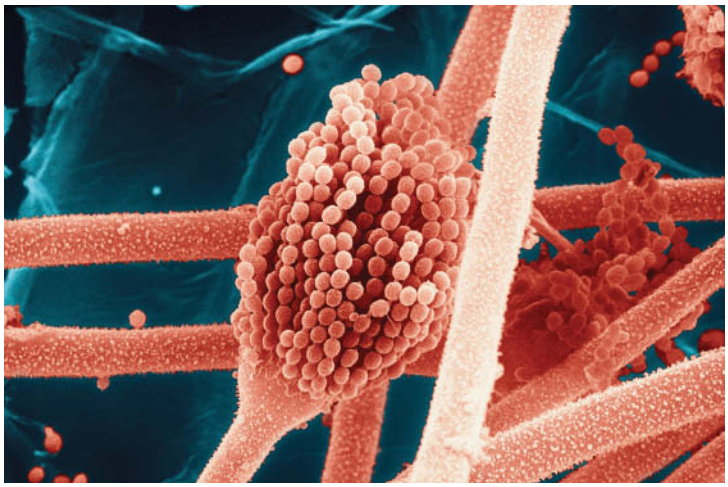
mold Multicellular fungi that form a filamentous branching growth.

Many types of **mold** grow on foods such as bread, cheese, and fruit. Molds produce toxins that can lead to food intoxication. More than 250 different mold toxins have been identified. Aflatoxin is a mold toxin that is among the most potent mutagens and carcinogens known (Figure 17.10). It is produced by the mold *Aspergillus flavus*. This mold commonly grows on corn, rice, wheat, peanuts, almonds, walnuts, sunflower seeds, and spices such as black pepper and coriander. Because the level of aflatoxin that may be present in foods in the United States is regulated to prevent

FIGURE 17.10 Mold toxin and liver cancer

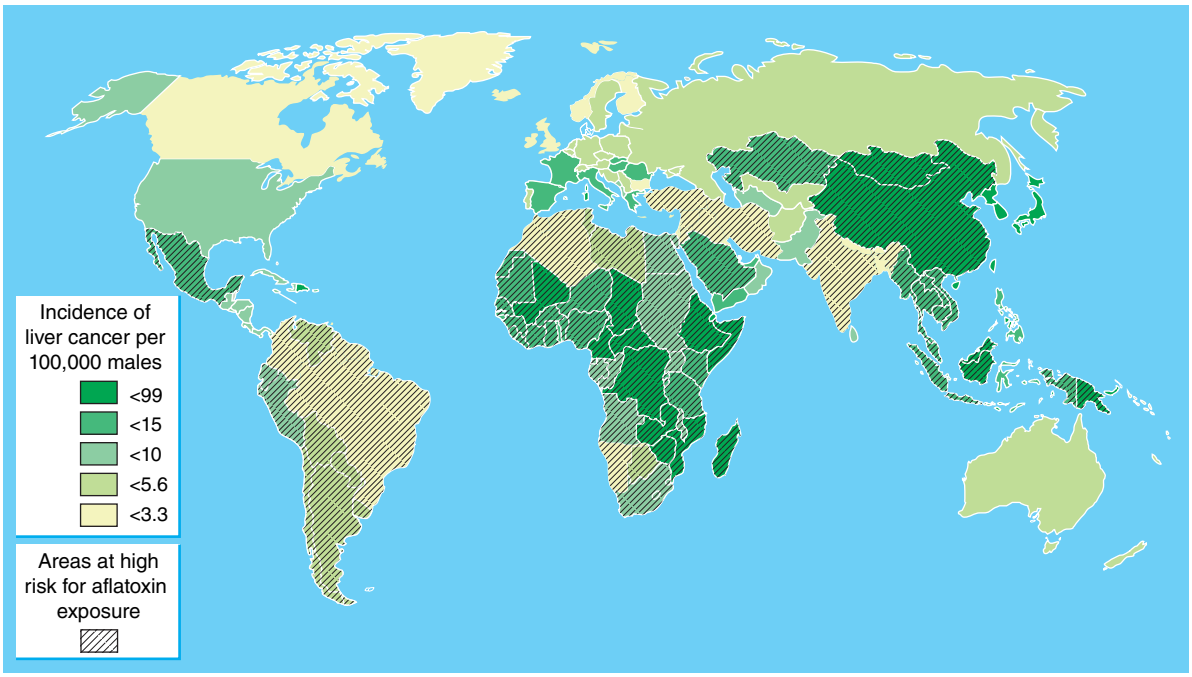
ANALYZE THE DATA

Is the relationship between liver cancer and aflatoxin exposure, shown on the map, proof that aflatoxin causes liver cancer? Why or why not?



BSIP/Photo Researchers, Inc.

A. The filamentous growths seen in this electron micrograph belong to the mold *Aspergillus flavus*, which produces aflatoxin.



B. Exposure to aflatoxin can lead to liver cancer. Many regions of the world with high rates of liver cancer also have high exposure to aflatoxin.[20]

toxicity, there has never been an outbreak of illness caused by aflatoxin in the United States, but it is a problem in developing countries.

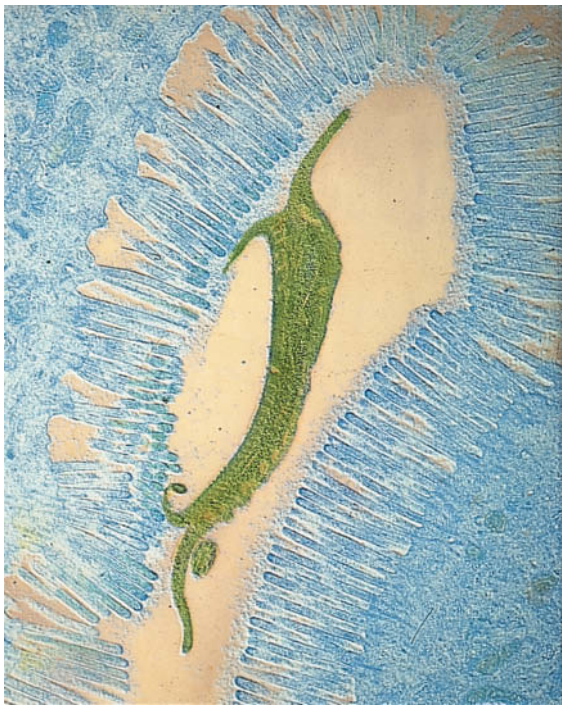
Cooking and freezing foods stop mold growth but do not destroy the mold toxins that have already been produced. If a food is moldy, it should be discarded, the area where it was stored should be cleaned, and neighboring foods should be checked to see if they have also become contaminated.

Parasites

Some **parasites** are tiny single-celled animals, whereas others are worms that are easily seen with the naked eye. Parasites that can be transmitted through consumption of contaminated food or water cause food-borne illness. *Giardia lamblia* (also called *Giardia duodenalis*) is a single-celled parasite that causes diarrhea and other GI symptoms (Figure 17.11). It is the most frequent cause of diarrhea not due to bacteria or viruses. *Giardia* is sometimes contracted by hikers who drink untreated water from streams contaminated with animal feces. *Giardia* infection is also becoming a problem in day-care centers where diapers are changed and hands and surfaces are not thoroughly washed.[6] *Cryptosporidium* is another single-celled parasite that causes diarrhea. It can be contracted by consuming water or food contaminated with the feces of humans or animals infected with the parasite.[21]

Trichinella spiralis is a parasite that was once commonly found in raw and undercooked pork and pork products. Once ingested, these small, worm-like organisms find their way to the intestine and eventually into the muscles, where they grow, causing flu-like symptoms, muscle weakness, fever, and fluid retention. Trichinosis, the disease caused by *Trichinella* infection, can be prevented by thoroughly cooking meat to kill the parasites before the meat is ingested. The parasites are also destroyed by curing, smoking, canning, or freezing. Current animal feeding practices have decreased the incidence of *Trichinella* in pork, but meat from game like bear and rabbit is still a source of this parasite.

Fish are another common source of parasitic infections. Fish can carry the larvae (the worm-like stage of an organism's life cycle) of parasites such as roundworms, flatworms, flukes, and tapeworms. One such infection, *anisakiasis*, is caused by the larval form of the small roundworm *Anisakis simplex*, or herring worm, found in raw fish.[6] Once consumed, these parasites burrow into the wall of the esophagus, stomach, or intestinal tract, causing severe abdominal pain. The fresher the fish is when it is eviscerated, the less likely it is to cause this disease, because the larvae move from the fish's stomach to its flesh only after the fish dies. Parasitic infections from fish can be avoided by consuming cooked fish or freezing fish for 72 hours before consumption. If raw fish is consumed, it should be very fresh (Figure 17.12).



CNRI/Science Photo Library/Photo Researchers

FIGURE 17.11 Giardia attached to the intestinal lining
This electron micrograph shows *Giardia* (green) attached to the microvilli of the human small intestine.

Hoi Fung Tsoi/Getty Images, Inc.

FIGURE 17.12 Raw fish can be hazardous
Although rare, the incidence of parasitic infections from fish has increased along with the popularity of eating raw fish, such as this sushi.

Prions

One of the strangest, yet rarest, food-borne illness is caused not by a microbe but by a protein, called a **prion**, that has folded improperly. Abnormal prions are believed to be the cause of mad cow disease, or bovine spongiform encephalopathy (BSE), a deadly degenerative neurological disease that affects cattle. BSE is thought to have originated from sheep that carried a similar disease called *scrapie*. It moved into cattle in Britain when they were fed protein supplements containing the remains of slaughtered, diseased sheep. People are believed to contract the human form of this disease, which is called *variant Creutzfeldt-Jakob disease* (*vCJD*), by consuming tissue from a cow infected with BSE.[22] High-risk tissues include brain and nervous tissue, intestines, eyes, and tonsils. Thus far, meat (if free of central nervous system tissue) and milk have

parasites Organisms that live at the expense of others.

prion A pathogenic protein that is the cause of degenerative brain diseases called *spongiform encephalopathies*. Prion is short for proteinaceous infectious particle.

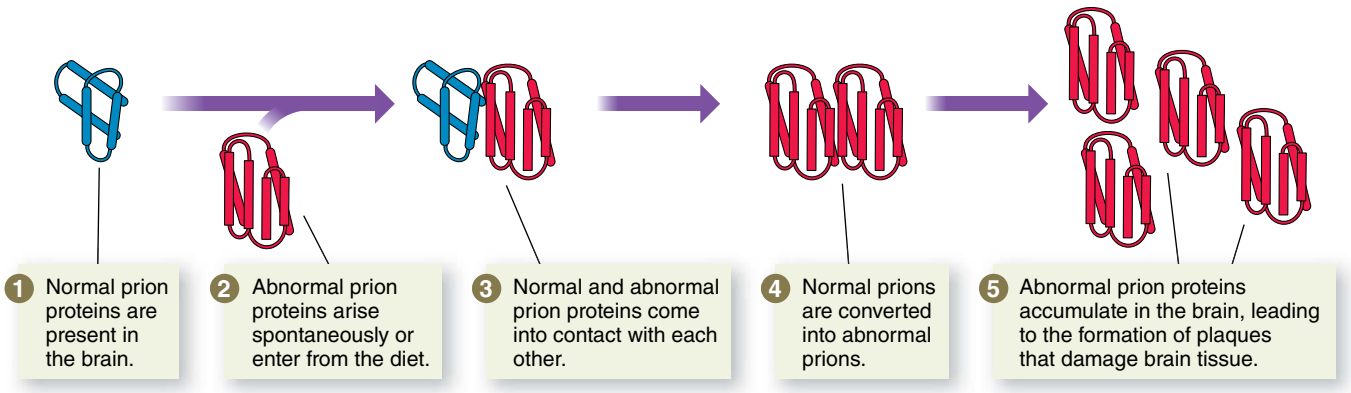


FIGURE 17.13 How prions multiply
When the improperly folded form of a prion is introduced into the brain after a person has eaten contaminated tissue, it can reproduce by corrupting neighboring proteins, essentially changing their shape so that they, too, become abnormal prions.

not been found to transmit vCJD.[6] Symptoms of vCJD occur about 10 years after consumption of contaminated tissue and begin as mood swings and numbness; within about 14 months the nervous tissue damage progresses to dementia and death.

The abnormal prions that cause BSE and vCJD differ from normal prion proteins in the way they are folded—that is, in their three-dimensional structure. These rogue proteins reproduce by corrupting normal neighboring proteins, essentially changing the way the normal prions fold, so they too become abnormal prions (Figure 17.13). Because the abnormal prion proteins are not degraded normally, they accumulate and form clumps called *plaques*. These plaques cause the deadly nervous tissue damage.

Even though cooking does not destroy prions, the risk of acquiring vCJD is extremely small. Safeguards are in place to prevent cattle in the United States from contracting BSE. These include restrictions on the import of animals and animal products from countries where BSE has occurred, restrictions on what can be included in cattle feed, and testing for BSE before meat is released into the food supply.[23] Several cows with BSE have been identified in the United States, but thus far there has been no known instance of U.S. beef causing a case of vCJD.[22] Even in Britain, where over 180,000 cows were infected, only 177 cases of vCJD have been identified.[22]

17.4 How to Reduce the Risk of Microbial Food-Borne Illness

LEARNING OBJECTIVES

- Discuss how proper refrigeration can reduce food-borne illness.
- Describe how safe handling can prevent cross-contamination.
- Explain how proper cooking and storage temperatures prevent food-borne illness.
- List three factors that could increase the risk of contracting food-borne illness from food served at a picnic.

Avoiding microbial food-borne illness requires knowledge of how contamination occurs and how to choose, store, handle, and cook food safely (Figure 17.14). The first critical control point in preventing food-borne illness at home is making safe selections at the store to reduce the contaminants that are brought into the home. Food should come from reputable vendors and appear fresh. Foods that are discolored or have an off smell and those in damaged packages should not be purchased or consumed. The same selection and handling guidelines used for food eaten at home should be used for choosing food consumed away from home.

Store Food Properly

Once selected, foods need to be stored appropriately. The goal is to keep foods from remaining at temperatures that promote bacterial growth. Refrigerator and freezer temperatures either limit or stop microbial growth (Figure 7.15). When transporting food from the store, manage temperatures to prevent cold foods from becoming overly warm and frozen foods from thawing. Once home, perishable food should be placed in a refrigerator with the temperature set between 38 and 40°F or a freezer set at 0°F. Most produce should be stored in the refrigerator. Fresh meat, poultry, and fish should be frozen immediately if it will not be used within a day or two. Processed meats such as hot dogs and bologna must also be kept refrigerated but can be kept longer than fresh meat.[24] Foods that are served cold should be kept cold, at 40°F or less, until they are served. Storing food in the refrigerator will slow microbial growth, but refrigerated food should be discarded if not used within the time frames shown in Table 17.5.

FIGURE 17.14 Fight Bac!
The Fight Bac! educational campaign recommends that consumers follow four steps—clean, separate, cook, and chill—to prevent food-borne illness.

Handle Food Safely

Preparing food in a clean kitchen keeps food safe by preventing cross-contamination. Hands, countertops, cutting boards, and utensils should be washed with warm soapy water before each food preparation step. Food should be thawed in the refrigerator, in the microwave oven, or under cool running water—not at room temperature, which favors microbial growth. Foods that are eaten raw should not be prepared on the same surfaces as foods that are going to be cooked. For example, if a chicken contaminated with *Salmonella* is cut up on a cutting board and the unwashed cutting board is then used to chop vegetables for a salad, the vegetables will become contaminated with *Salmonella*. When the chicken is cooked, the bacteria will be killed, but the contaminated vegetables are not cooked, so the bacteria can grow and cause food-borne illness. Cross-contamination can also occur when uncooked foods

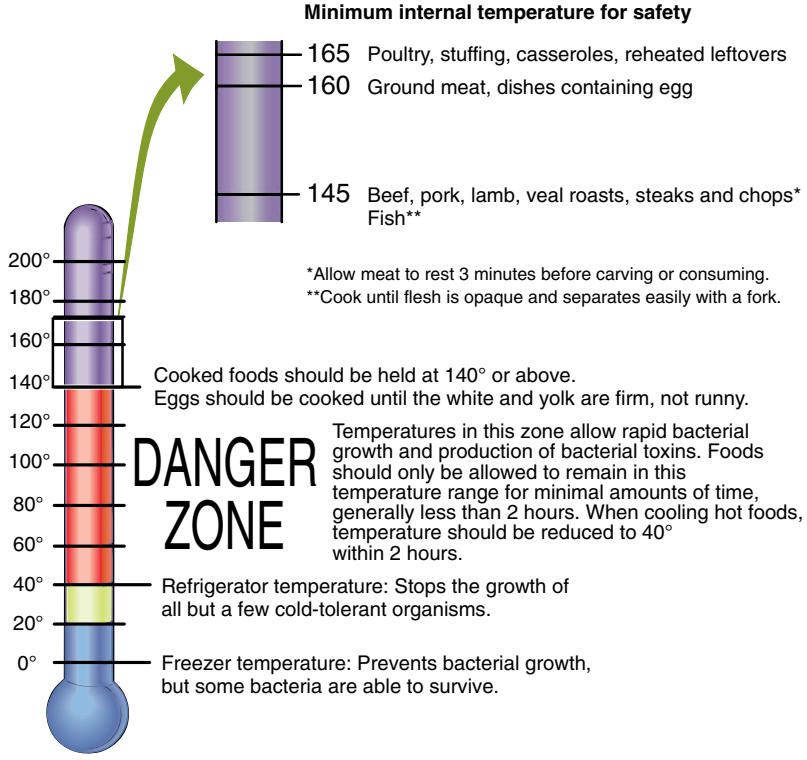


FIGURE 17.15 Temperature and bacterial growth
Temperature is one of the best weapons consumers have for preventing food-borne illness. Minimizing the time food temperatures remain in the danger zone—between 40 and 140°F—reduces bacterial growth and therefore the risk of food-borne illness. Cooking meat, poultry, and casseroles and reheating leftovers until they reach the internal temperatures shown here will ensure that microbes have been killed.[26]

TABLE 17.5 Safe Food Storage Times[24,25]

Food	Safe to refrigerate (40°F) for	Safe to freeze (0°F) for*
Eggs, fresh, in shell	3–5 weeks	Do not freeze. Instead, beat whites and yolks together and then freeze
Soups and stews	3–4 days	2–3 months
Hot dogs		
Opened package	1 week	1–2 months
Unopened package	2 weeks	1–2 months
Luncheon meat		
Opened package or deli sliced	3–5 days	1–2 months
Unopened package	2 weeks	1–2 months
Bacon and Sausage		
Bacon	7 days	1 month
Sausage, raw—from chicken, turkey, pork, or beef	1–2 days	1–2 months
Hamburger and other ground meats	1–2 days	3–4 months
Fresh beef, veal, lamb, and pork		
Steaks	3–5 days	6–12 months
Chops	3–5 days	4–6 months
Roasts	3–5 days	4–12 months
Fresh poultry		
Chicken or turkey, whole	1–2 days	1 year
Chicken or turkey, pieces	1–2 days	9 months
Leftovers		
Cooked meat or poultry	3–4 days	2–6 months
Chicken nuggets or patties	3–4 days	1–3 months
Pizza	3–4 days	1–2 months

*The guidelines for freezer storage are for quality only. Frozen foods remain safe indefinitely.

containing live microbes come in contact with foods that have already been cooked. Therefore, cooked meat should never be returned to the same dish that held the raw meat, and sauces used to marinate uncooked foods should never be used as a sauce on cooked food. To remind consumers how to handle meat, the packaging is labeled with safe handling guidelines.

Cook Food Thoroughly

Cooking is one of the most important steps in preventing food-borne illness. Heat will destroy most harmful microorganisms. To ensure that meat is cooked thoroughly, a meat thermometer should be used; color is not a good indicator of safety. Heating foods to the recommended temperature kills microbes and destroys toxins (see Figure 17.15). After meat is removed from a grill, oven, or other heat source, it should rest for about 3 minutes before it is consumed. During this time, its temperature remains constant or continues to rise, destroying harmful microbes.[26] Fish should be cooked until the flesh is opaque and separates easily with a fork. Eggs should not be eaten raw, since *Salmonella* can contaminate the inside of the shell; they should be cooked until the yolk and white are firm.[26]

Cooked food should be kept hot, at more than 140°F, until it is served and then chilled quickly before storage. Leftover cooked food should be refrigerated as soon as possible after it has been served. As a general rule, food should not be left unrefrigerated for more than two hours, or for more than one hour if the ambient temperature is above 90°F.[27] The temperatures conducive to bacterial growth are the temperatures at which food is usually kept between service and storage. Large portions of food should be divided before refrigeration so they will cool quickly. Most leftovers should only be kept for a few days (see Table 17.5). When leftovers are reheated, they should be heated to 165°F to destroy any bacteria that may have grown in them. Tips for the safe selection and handling of food at home are summarized in Table 17.6

TABLE 17.6 Tips for the Safe Selection and Handling of Food

Choose foods wisely
Voluntary freshness dates should be checked and foods with expired dates avoided. Jars should be closed and seals unbroken. Cans that are rusted, dented, or bulging should be rejected. Frozen foods should not contain frost or ice crystals, and food packaging should be secure. Frozen foods should be selected from below the frost line in the freezer. When shopping, cold foods should be purchased last.
Store foods properly
Fresh or frozen foods brought from the store should be refrigerated or frozen immediately at the proper temperature. Food that has been in your refrigerator for longer than is safe should be discarded.
Wash
Hands, cooking utensils, and surfaces should be washed with warm soapy water before each food preparation step. This will prevent cross-contamination.
Thaw
Foods should be thawed in the refrigerator or microwave or under cool running water.
Cook thoroughly
Cooking temperatures should be checked. Thorough cooking destroys most bacteria, toxins, viruses, and parasites.
Refrigerate promptly
Cooked food can be recontaminated, so it should be refrigerated as soon as possible after it is served.
Reheat thoroughly
Foods should be reheated to 165°F to destroy microorganisms that have recontaminated cooked foods and toxins that have been produced.
When in doubt, throw it out.

Food Safety Away from Home

When you prepare your own food, you can monitor the safety of the ingredients and food preparation steps, but at restaurants, picnics, and potlucks, you must rely on others to keep your food safe. Consumers should choose restaurants with safety in mind. Restaurants should be clean, and cooked foods should be served hot. Cafeteria steam tables should be kept hot enough that the water is steaming and food is kept above 140°F. Cold foods such as salad bar items should be kept refrigerated or on ice to keep food at 40°F or colder.

Picnics, potlucks, and other large events where food is served provide a prime opportunity for microbes to flourish because food is often left at room temperature or in the sun for hours before it is consumed. Foods that last well without refrigeration, such as fresh fruits and vegetables, breads, and crackers, should be selected for these occasions (see **Critical Thinking: Safe Picnic Choices**).

Food safety is also a concern when food must be carried out of the home. Any food that is transported should be kept cold. Lunches should be transported to and from work or school in a cooler or an insulated bag. They should be refrigerated upon arrival or kept cold with ice packs. Most foods that are returned uneaten from work or school should be thrown out and not saved for another day.

17.5 Agricultural and Industrial Chemicals in Food

LEARNING OBJECTIVES

- Illustrate how contaminants move through the food chain and into our foods.
- Discuss how pesticide use is regulated in the United States.
- Compare the risks and benefits of using pesticides with those of growing food organically.
- Describe how consumers can minimize the risks of exposure to chemical contaminants.

CRITICAL THINKING — Safe Picnic Choices

© Edward ONeil Photography Inc./iStockphoto

Tamika is planning a potluck picnic. She is worried about food safety, so she tries to apply the HACCP principles.

▼

For each food in the picnic menu below, indicate whether it might pose a risk of food-borne illness.

PICNIC MENU

FOOD	IS THIS FOOD A RISK?	WHY OR WHY NOT?
Chips		
Chicken salad		
Fried chicken		
Tamales		
Raw vegetables and ranch dressing		
Cheese and crackers		
Apple pie		
Cookies		
Mushrooms stuffed with crab meat		
Fruit salad		

CRITICAL THINKING QUESTIONS

- **What could Tamika do at the picnic to reduce the growth of bacteria already present in the food?**
- **After the picnic, which foods will be safe for Tamika to eat as leftovers?**

iProfile Use iProfile to find the number of calories in your favorite picnic foods.

Chemicals used in agricultural production and industrial wastes contaminate the environment and can find their way into the food supply. How harmful these chemicals are depends on how long they persist in the environment and whether they accumulate in the organisms that consume them or can be broken down and excreted by these organisms. Some contaminants are eliminated from the environment quickly because they are broken down by microorganisms or chemical reactions. Others remain in the environment for very long periods, and when taken up by plants and small animals, they are not metabolized or excreted. For example, fat-soluble contaminants concentrate in body fat and cannot be excreted. When contaminated plants or small animals are consumed by larger animals that are in turn eaten by still larger animals, the contaminants accumulate, reaching higher concentrations at each level of the food chain (Figure 17.16). This process is called **bioaccumulation**. Because the toxins are not eliminated from the body, the greater the amount consumed, the greater the amount present in the body.

bioaccumulation The process by which compounds accumulate or build up in an organism faster than they can be broken down or excreted.

pesticide Any substance or mixture of substances intended to prevent, destroy, repel, or mitigate insect, animal, plant, fungal, or microbial pests.

Risks and Benefits of Pesticides

Pesticides are applied to crops growing in the field to prevent plant diseases and insect infestations and also applied to produce after harvesting to prevent spoilage and extend shelf life. Residues of these substances remain on the fruits and vegetables that reach consumers. Pesticides can also travel from the fields where they are applied into water supplies, soil, and other parts of the environment, so pesticide residues are found not only on treated produce but also in meat, poultry, fish, and dairy products.

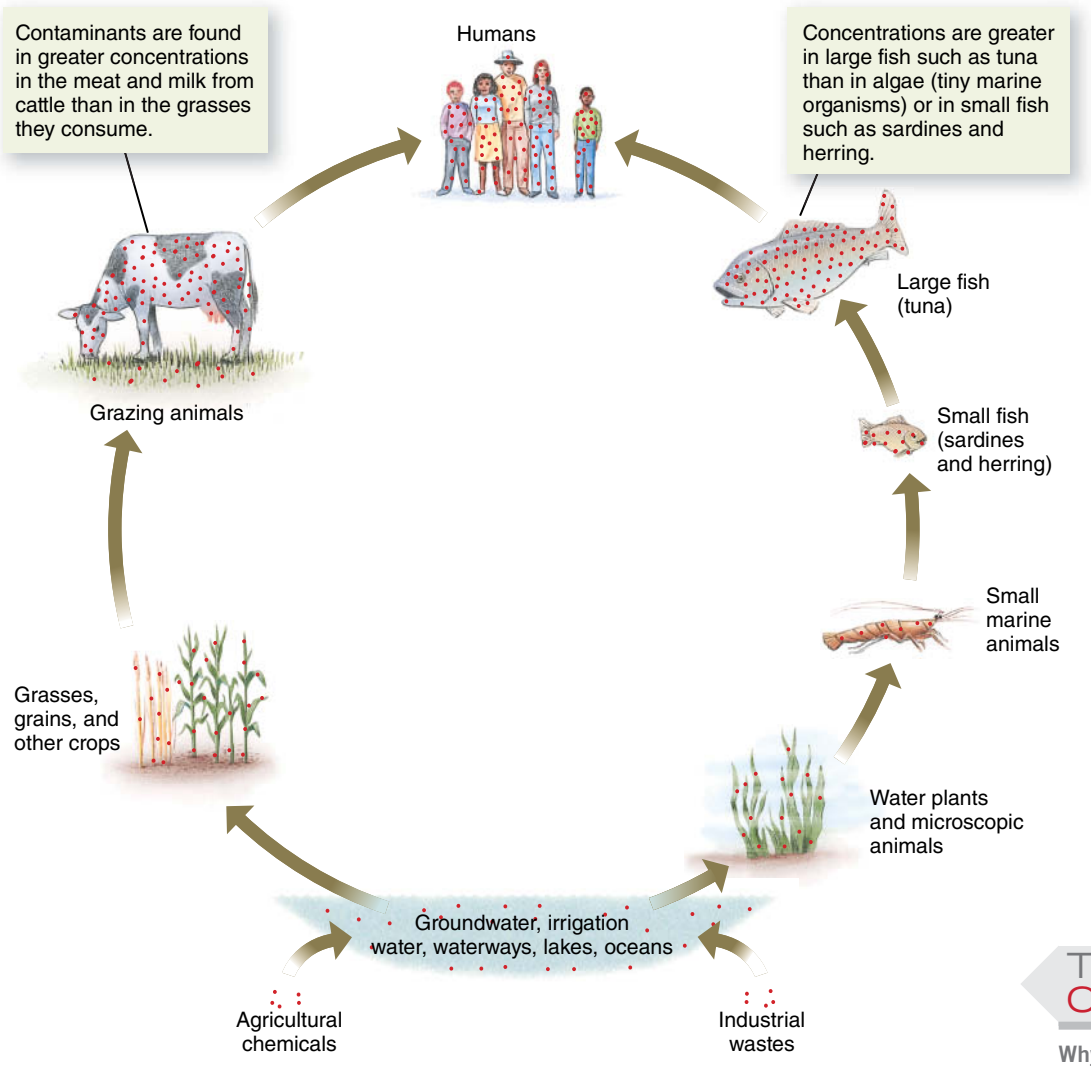


FIGURE 17.16 Contaminants in the food chain
Agricultural chemicals and industrial pollutants that contaminate the water supply enter the food chain and accumulate as they are passed through the chain. An animal later in the food chain has higher concentrations of these contaminants because it consumes all the contaminants that have been eaten by organisms at lower feeding levels.

THINK CRITICALLY

Why are you more likely to consume harmful amounts of toxins by eating tuna than by eating shrimp?

Controlling Pesticide Exposure The EPA, the FDA, and the USDA share the responsibility for limiting consumers' exposure to pesticides. The EPA determines the safety and effectiveness of pesticides and sets limits on the amount of pesticide residues that may remain in or on feed crops, as well as in raw and processed foods marketed in the United States.[28] These limits or **pesticide tolerances** are based on the potential risks to human health posed by a pesticide and are set well below the level that might cause harm to infants, children, adults, or the environment.[29]

pesticide tolerances The maximum amount of pesticide residues that may legally remain in or on foods marketed in the United States; set by the EPA.

While the EPA sets tolerances, the FDA and USDA monitor pesticide residues and enforce tolerances in both domestic and imported foods. Domestic samples are collected from growers, packers, and distributors; import samples are collected at the point of entry into the U.S. market. If domestic samples are found to have illegal residues at a level above an EPA tolerance, the entire lot of food is removed from the market. If imported foods are found to have illegal residues, they are refused entry into U.S. commerce.[30] In addition to this regulatory monitoring that samples raw, unaltered foods, the FDA's Total Diet Study measures pesticide residues in foods that are prepared for consumption. Samples are washed, peeled, and/or cooked before analysis, to simulate how the consumer would handle the food before consumption. The Total Diet Study samples food as "market baskets." Each

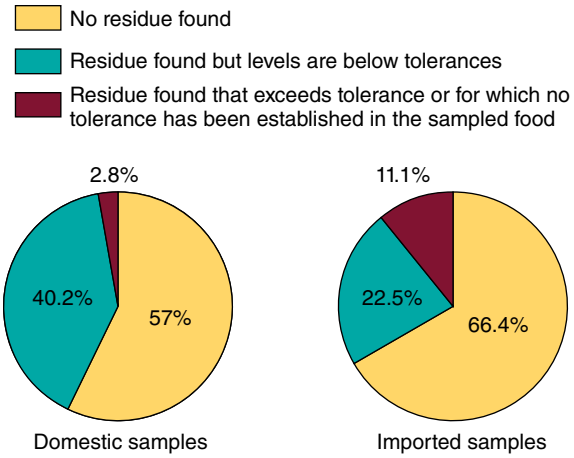


FIGURE 17.17 Pesticide tolerances
An analysis of samples of domestically produced food and imported food from 107 countries found no pesticide residues in 57.0% of domestic and 66.4% of imported samples.[30]

market basket is made up of about 300 different foods selected to represent the average U.S. consumer's diet. In addition to being analyzed for pesticide residues, this market basket of foods is also analyzed for nutrients, toxins, industrial chemicals, and other chemical contaminants.[30]

In general, the amounts of pesticides to which people are exposed through foods are small. The USDA's Pesticide Data Program has found that over 99% of products sampled had residues below established EPA tolerances.[31] The FDA's Pesticide Monitoring Program has found pesticide residue levels in both domestic and imported foods to be well below federally permitted limits (Figure 17.17).[30] Despite this, some individuals and special-interest groups are concerned that the pesticides remaining on foods pose a risk to human health. Repeated consumption of large doses of any one pesticide could be harmful, but this is unlikely because most people consume a variety of foods produced using many different pesticides.

How Pesticide Risks Are Being Reduced

To reduce the risks posed by pesticides, new, safer, more effective chemical pesticides are being developed, and the use of older, more toxic products is decreasing in the United States. One class of pesticide that is less likely to be harmful is biopesticides. These include naturally occurring substances that control pests, microorganisms that control pests, and pesticidal substances that are produced by plants through **genetic engineering**. In addition to developing safer pesticides, production methods are being implemented to make low-pesticide and pesticide-free produce available to the consumer.

genetic engineering A set of techniques used to manipulate DNA for the purpose of changing the characteristics of an organism or creating a new product.

Natural Toxins

Many toxins that occur in plants function as natural pesticides that offer protection from bacteria, molds, and insect pests. These naturally pest-resistant crops are advantageous in developing countries because they thrive without the use of expensive added pesticides. Plants high in natural pesticides are being produced through special breeding programs as well as genetic engineering. The natural toxins in plants can also be isolated and applied to crops like synthetic pesticides.

As with all chemical toxins, natural toxins move through the food supply. For example, a cow that has foraged on toxic plants can pass the toxin into her milk and poison the consumer of the milk. Abraham Lincoln's mother died from drinking milk from a cow that had eaten poisonous snakeroot plants. The potential for toxicity, however, depends on the dose of toxin and the health of the consumer. Most natural toxins in the food supply are consumed in doses that pose little risk to the consumer.

integrated pest management (IPM) A method of agricultural pest control that integrates nonchemical and chemical techniques.

Integrated Pest Management

Integrated pest management (IPM) is a method of agricultural pest control that combines chemical and nonchemical methods and emphasizes the use of natural toxins and effective pesticide application. For example, increasing the use of naturally pest-resistant crop varieties that thrive without the use of added pesticides can reduce costs and do less environmental damage. IPM programs use information about the life cycles of pests and their interactions with the environment to manage pest damage economically and with the least possible hazard to people, property, and the environment.

organic food Food that is produced, processed, and handled in accordance with the standards of the USDA National Organic Program.

Organic Methods

Organic food production methods emphasize recycling of resources, conservation of soil and water to protect the environment, and conservation of biodiversity. Organic food is produced without using most conventional pesticides, fertilizers made with synthetic ingredients, antibiotics, or growth hormones. The USDA's National Organic Program has developed standards for organic foods. These national standards define both substances approved for and prohibited from use in organic food production. For example, an organic food may not include ingredients that are treated with irradiation, produced by genetic modification, or grown using sewage sludge.[32] Certain natural pesticides and other manufactured agents are permitted.

Labeling term	Meaning
100% organic	Contains 100% organically produced raw or processed ingredients.
Organic	Contains at least 95% organically produced raw or processed ingredients.
Made with organic ingredients	Contains at least 70% organically produced ingredients.

FIGURE 17.18 Labeling organic foods
Agricultural products meeting the definition of "100% organic" or "organic" may display the USDA organic seal shown here.

Farming and processing operations that produce and handle foods labeled as organic must be certified by the USDA (Figure 17.18).

Organic farming techniques reduce the exposure of farm workers to pesticides and decrease the quantity of pesticides introduced into the food supply and the environment. However, organic foods are not risk-free. Animal manure is often used for fertilizer and run-off can pollute lakes and streams. To reduce any risk to consumers, manure applied to land used for crops intended for human consumption must be composted, which reduces the number of pathogens. Despite the fact that synthetic pesticides are not applied to organic crops, traces of these and other chemicals can be introduced into organically grown foods by irrigation water, rain, and a variety of other sources. The threshold for pesticide residues in organic foods is set at 5% of the EPA's pesticide-residue tolerance (see **Debate: Should You Go Organic?**).[32]

Antibiotics and Hormones in Food

Antibiotics and hormones are administered to animals to improve health, increase growth, or otherwise enhance food production. To prevent these chemicals from being passed on to consumers, both the types of drugs used and when they can be administered are regulated, and animal tissues are monitored for drug residues.[39]

Animals are treated with antibiotics when they are sick, but for decades animals have also been given antibiotics to prevent disease and promote growth. This treatment increases the amount of meat produced and reduces costs, but if it is used improperly, antibiotic residues can remain in the meat. In addition, the overuse of antibiotics in animals can contribute to the development of antibiotic-resistant strains of bacteria. When exposed to an antibiotic, bacteria that are resistant to it survive and produce offspring that are also resistant. If these antibiotic-resistant bacteria infect humans, the resulting illness cannot be treated with that antibiotic. To address the problem of antibiotic resistance, the FDA has taken steps to phase out the use of antibiotics for growth enhancement of healthy livestock; antibiotics will still be available to treat sick animals, but only with a veterinary prescription.[40]

Hormones are used to increase weight gain in sheep and cattle and milk production in dairy cows. Some naturally occurring hormones such as estrogen and testosterone are used in slow-release form, and levels in the treated animals are no higher than in untreated animals. Before synthetic hormones can be used, it must be demonstrated that residues in meat are within the safe limits. A synthetic hormone that has created public concern is genetically engineered bovine somatotropin (bST). Cows naturally produce somatotropin, a hormone that stimulates milk production. Genetically engineered bST is produced by bacteria and injected into cows to increase milk production. Consumer groups contend that genetically engineered bST causes health problems for the cows and for humans who consume milk or meat from the cows. An FDA review of the effect of bST concluded that it causes no serious long-term health effects in cows, and that milk and meat from bST-treated cows are not health risks to consumers.[41] The FDA does not require milk from bST-treated cows to be specially labeled,

DEBATE

Should You Go Organic?

The sale of organic foods is on the rise. Organic foods account for over 4% of total U.S. food sales, and the top-selling category of organically grown food is fresh fruits and vegetables.[33] This trend is fueled by concern about food safety, nutritional health, and the environment. Is organic food safer, more nutritious, and more environmentally friendly than conventionally produced food?

Some people choose organic fruits and vegetables because they believe they are safer than traditional products. If *safer* means fewer chemical contaminants, then organic produce is a good choice. It contains fewer pesticides and is significantly lower in nitrates than traditionally grown foods.[34] But it can be argued that there is little evidence that the current levels of pesticide exposure from conventional produce are a risk to human health (see Figure 17.17). And there are other contamination risks associated with organic foods. For example, manure is often used for fertilizer, and if the manure is not treated properly, it can contain pathogenic bacteria.[35]

Many consumers believe that organically produced food is not only safer but also more nutritious. *Nutritious* can mean that it is more effective at preventing nutrition-related diseases. When consumption of organic food is compared with consumption of conventionally produced foods, the majority of studies do not show organic foods to be beneficial in terms of preventing nutrition-related diseases.[36] Research data on the nutrient content of organically produced food are ambiguous. Some studies report that organically produced foods contain more nutrients than conventionally produced foods,[34] whereas other studies have found no consistent differences in nutrient content.[37] This confusion is not surprising because many factors—including growing conditions, season, and the fertilizer regime and methods used for crop protection (for example, use of pesticides and herbicides)—affect the nutritional composition of fruits and vegetables. Nutrient content is also affected by how the food is stored, transported, and processed prior to consumption.

What about the environment? Instead of chemical pesticides and fertilizers, organic farming relies on crop rotation, compost, and cover crops to maintain the soil. The result is preservation of the soil, so crops can be grown far into the future, and reduction in the amounts of chemicals released into the environment. But organic growing still impacts the environment. As occurs with conventionally grown produce, manure runoff can pollute waterways, and organic food, like conventional food, is often shipped long distances, using energy and generating pollution. Organic farming may also require more land to produce the same amount of food because yields are typically lower than conventional yields.[38]

Is a diet based on organic foods safer, more nutritious, and better for the environment? We can assume that both conventional and organic foods sold in the United States are generally safe. Whether organic is more nutritious depends not only on individual foods but on the diet as a whole. If your choices of organic foods are limited by availability or cost, then choosing only organic may limit nutrient intake. Are organic foods better for the environment? They reduce pesticide and fertilizer use, but if organic foods are not available locally, the environmental cost of transporting them is no different than it is for conventional foods.

THINK CRITICALLY: Are these organic onions that were shipped across the country a better environmental choice than conventionally grown onions from a farm across town?

Drew Rush/NG Image Collection

but companies may voluntarily label their products as long as the labeling is truthful and not misleading (Figure 17.19).

Contamination from Industrial Wastes

Industrial chemicals that contaminate the environment find their way into the food supply. Fish accumulate substances from the water in which they live and feed. Shellfish accumulate contaminants because they feed by passing large volumes of water through their bodies. Pollutants in the water can also contaminate crops and move through the food chain into meat and milk (see Figure 17.16).

One group of industrial chemicals that pollutes the environment is **polychlorinated biphenyls (PCBs)**. Prior to the 1970s, these chemicals were used in the manufacture of electrical capacitors and transformers, plasticizers, waxes, and paper. PCBs in runoff from manufacturing plants contaminated water, particularly near the Great Lakes. PCBs are no longer produced, but because they do not degrade, they are still in the environment and accumulate in fish caught in contaminated waters.

PCB exposure can cause skin conditions, liver damage, and certain kinds of cancer. It is a particular problem for pregnant and lactating women, because prenatal exposure and consumption of contaminated breast milk can damage the nervous system and cause learning deficits in children. The American Academy of Pediatrics has concluded that the benefits of breast-feeding outweigh the risks of low levels of PCBs. They recommend that breast-feeding women in areas where high exposures of PCBs have occurred check with the local health department for recommendations on fish consumption.

Other contaminants from manufacturing, such as chlordane (used to control termites), radioactive substances such as strontium-90, and toxic metals such as cadmium, lead, arsenic, and mercury, have also found their way into fish and shellfish. Cadmium and lead can interfere with the absorption of other minerals and can have a direct toxic effect: Cadmium can cause kidney damage; lead can impair brain development. Arsenic is believed to contribute to cancer development, and mercury, which is found in high concentrations in swordfish, king mackerel, tilefish, and shark, damages nerve cells (Figure 17.20).[42] Large fish at the top of the food chain are more likely to contain high levels of industrial contaminants, but shellfish also accumulate contaminants.

Courtesy Lori Smolin

FIGURE 17.19 Bovine somatotropin
Milk from cows treated with genetically engineered bST is indistinguishable from other milk, but dairies that do not use bST may choose to label their products as bST-free.

How to Choose Wisely to Minimize Agricultural and Industrial Contaminants

Even though individuals cannot detect chemicals in food, consumers can reduce the contaminants they consume by choosing and preparing food carefully. One of the easiest ways to reduce risk is to choose a wide variety of foods, thus avoiding excessive consumption of any one contaminant.

Although some consumers are concerned about the consumption of pesticide residues, the health risk of eliminating foods from the diet that may contain pesticide residues, such as fresh

polychlorinated biphenyls (PCBs) Carcinogenic industrial compounds that have found their way into the environment and, subsequently, the food supply. Repeated ingestion causes them to accumulate in biological tissues over time.

LIFE CYCLE

© Rafal Dubiel/iStockphoto

- Eat 8 to 12 oz (two or three servings) of a variety of fish* weekly.
- Choose fish low in mercury, such as salmon, shrimp, pollock, tuna (light canned), tilapia, catfish, and cod.
- Avoid the four types of fish that are highest in mercury (tilefish, shark, swordfish, and king mackerel) and limit white (albacore) tuna to 6 oz/week.
- Pay attention to fish advisories when eating fish caught from streams, rivers, and lakes. If advice isn't available, adults should limit such fish to 6 oz/week and young children to 1 to 3 oz/week and not eat other fish that week.
- When adding more fish to your diet, be sure to stay within your calorie needs.

*"Fish" refers to both fish and shellfish

FIGURE 17.20 Fish consumption advice for pregnant women and young children
By following the recommendations shown here, pregnant women and young children can enjoy the health benefits of eating fish without the risk of excessive mercury exposure.[42] The portion sizes of fish for young children should be appropriate for their age and calorie needs.

fruits and vegetables, is probably greater than that of the pesticide exposure. To reduce exposure to pesticide residues in produce, consumers can choose organic foods or locally grown fruits and vegetables. Locally grown produce contains fewer pesticides because the pesticides used to prevent spoilage and extend the shelf life of shipped produce are not needed. Pesticides on conventionally grown produce can be removed or reduced by peeling or washing with tap water and scrubbing with a brush if appropriate. For leafy vegetables such as lettuce and cabbage, the outer leaves can be removed and discarded. Some produce, such as cucumbers, apples, eggplant, squash, and tomatoes, is coated with wax to maintain freshness by sealing in moisture, but wax also seals in pesticides. Much of the wax can be removed by rinsing produce in warm water and scrubbing it with a brush, but to eliminate all wax, the produce must be peeled. Although peeling fruits and vegetables eliminates some pesticides, it also eliminates some fiber and micronutrients.

Intake of pesticides and other chemical pollutants from fish and seafood products can also be minimized by choosing wisely and consuming a variety of fish (see Figure 17.20). Smaller species of fish are safer because they are earlier in the food chain, and smaller fish within a species are safer because they are younger and hence have had less time to accumulate contaminants. The safest fish are saltwater varieties caught well offshore, away from polluted waters. Freshwater fish and saltwater fish that live near shore or spend part of their life cycle in fresh water are more likely to contain contaminants. Migratory fish such as striped bass and bluefish are a problem because they may contain contaminants even when they are caught in clean water well offshore.

Most toxins concentrate in adipose tissue, so amounts can be reduced by removing the skin, fatty material, and dark meat from fish (and trimming fat from meat and removing skin from poultry). The use of cooking methods such as broiling, poaching, boiling, and baking allows the fatty portions of the fish and other meats to drain out. Do not eat the "tomalley" in lobster. The tomalley, a green paste inside the abdominal cavity of a cooked lobster, serves as the liver and pancreas and is the organ in which toxins accumulate. The analogous organ in blue crabs, called the "mustard" because of its yellow color, should also be avoided.

17.6 Technology for Keeping Food Safe

LEARNING OBJECTIVES

- Describe how temperature is used to prevent food spoilage.
- Discuss how irradiation preserves food.
- Explain how packaging protects food.
- Compare the risks and benefits of food additives.

Advances in food and agricultural technology have improved the safety and availability of foods. This technology allows food to be stored for long periods, adds nutrients lacking in the diet, and creates new food products. It has helped ensure that food is available even if the local growing season is not ideal. Without technology, the food supply would include only locally grown foods that must be eaten soon after harvest or slaughter. While this has some appeal, it would limit the variety of foods in the diet, particularly during the winter months, and increase the risk for malnutrition if food production were interrupted by a natural or man-made disaster.

Food spoilage occurs when the taste, texture, or nutritional value of food changes as a result of either enzymes that are naturally present in the food or bacteria or mold that grow on the food. For thousands of years, humans have treated food in order to prevent spoilage. Techniques that preserve food work by destroying enzymes present in the food, by killing microbes, or by slowing microbial growth. As shown in Table 17.7, the acronym FAT TOM reminds us of the conditions required for microbial growth. Most food preservation techniques modify one or more of these factors to stop or slow microbial growth. Many of the oldest methods of food preservation—including heating, cooling, drying, smoking, **fermentation**, and adding sugar or salt—are still used today. In addition, new methods of improving food quality and preventing spoilage and contamination, such as irradiation and specialized packaging, have been developed. While all these technologies offer benefits, they can also create risks. Some risk arises when substances find their way into food, either accidentally or as a normal part of the production process. The

fermentation A process in which microorganisms metabolize components of a food and thus change the composition, taste, and storage properties of the food.

TABLE 17.7 FAT TOM: Factors That Affect Microbial Growth

Food	Food contains nutrients that promote bacterial growth.
Acidity	Most bacteria grow best at a pH near neutral. Some food additives, such as citric acid and ascorbic acid (vitamin C), are acids, which prevent microbial growth by lowering the pH of food.
Time	The longer a food sits at an optimum growth temperature, the more bacteria it will contain. Food should not be left in the temperature danger zone for more than two hours.
Temperature	The high temperatures of canning, cooking, and pasteurization kill microbes, and the low temperatures of freezing and refrigeration slow or stop microbial growth.
Oxygen	In order to grow, most bacteria need oxygen, so packaging that eliminates oxygen prevents their growth.
Moisture	Bacteria need water to grow, so preservation methods such as drying or the use of high concentrations of salt or sugar, which draw water away by osmosis, prevent bacteria from growing.

FDA considers any substance that can be expected to become part of a food a **food additive** and regulates its use. Substances that enter food unexpectedly are considered **accidental contaminants** and are not regulated.

food additive A substance that is intentionally added to or can reasonably be expected to become a component of a food during processing.

accidental contaminant A substance not regulated by the FDA that unexpectedly enters the food supply.

aseptic processing A method that places sterilized food in a sterilized package using a sterile process.

polycyclic aromatic hydrocarbons (PAHs) A class of carcinogenic substances produced during cooking when there is incomplete combustion of organic materials—such as when fat drips on a grill.

heterocyclic amines (HCAs) A class of carcinogenic substances produced when there is incomplete combustion of amino acids during the cooking of meats—such as when meat is charred.

How Temperature Keeps Food Safe

Cooking food is one of the oldest methods of ensuring food safety. It kills disease-causing organisms and destroys toxins. Other preservation techniques that rely on high temperature to kill microbes include canning, pasteurization, sterilization, and **aseptic processing**. Aseptic processing heats foods to temperatures that result in sterilization. The sterilized foods are then placed in sterilized packages using sterilized packaging equipment. Aseptic processing is currently used to produce boxes of sterile milk and juices (Figure 17.21). These can remain free of microbial contamination at room temperature for years. Pasteurization kills disease-causing bacteria but does not result in sterilization, so over time, pasteurized products will spoil (see **Science Applied: Pasteurization: From Spoiled Wine to Safe Milk**). Lowering food temperatures by refrigeration or freezing also preserves food and protects consumers but rather than killing microbes these cold temperatures slow or stop microbial growth.

Preservation techniques that rely on temperature benefit us by providing appealing, safe food, but they are not risk-free, particularly if used incorrectly. If foods are not heated long enough or to a high enough temperature, or if they are not kept cold enough, there is a risk of microbial food-borne illness. In addition, some types of cooking can also generate hazardous chemicals. These are considered accidental contaminants, so they are not regulated by the FDA. One group of carcinogenic chemicals produced during cooking is the **polycyclic aromatic hydrocarbons (PAHs)**. These are formed when fat drips onto the flame of a grill and burns. They rise with the smoke and are deposited on the surface of the food. Grilled meats are therefore high in PAHs. PAH formation can be minimized by selecting lower-fat meats and using a layer of aluminum foil to prevent fat from dripping on the coals.

Broiled foods, which are cooked with the heat source at the top, are low in PAHs. However, broiling and other methods of high-temperature cooking can result in another potential hazard—**heterocyclic amines (HCAs)**, such as benzopyrene. HCAs are formed from the burning of amino acids and other substances in meats. Well-done meat and meat cooked using hotter temperatures contain greater amounts. HCA formation can be reduced by precooking meat, marinating meat before cooking, cooking at lower temperatures, and reducing cooking time by using smaller pieces of meat and avoiding overcooking. The cooking temperatures recommended by the FDA are designed to prevent microbial food-borne illness and minimize the production of PAHs and HCAs (see Figure 17.15).

Another contaminant formed during food preparation is acrylamide. It forms as a result of chemical reactions during high-temperature baking or frying, particularly in carbohydrate-rich foods. The highest levels of acrylamide are found in French fries and snack chips. Smaller amounts are found in coffee and in foods made from grains, such as breakfast cereal and cookies. High doses of acrylamide have been found to cause cancer and reproductive problems in

George Semple

FIGURE 17.21 Aseptic packaging
If unopened, milk and juice in aseptic packages can be stored for long periods without refrigeration.

SCIENCE APPLIED

Pasteurization: From Spoiled Wine to Safe Milk

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

In 1857, French sailors mutinied because wine supplies were spoiling after only a few weeks at sea. Napoleon recognized this problem as a threat to his hopes for world conquest, so he turned to Louis Pasteur for help.

Jean Loup Charmet/SPL/Photo Researchers

This painting depicts Louis Pasteur studying the souring of wine.

THE SCIENCE

To study the problem, Pasteur traveled to a vineyard in Arbois, France, where spoilage was causing considerable economic losses for the wine industry. By examining the spoiled wine under a microscope, Pasteur was able to demonstrate the presence of certain strains of microorganisms (see figure). He suggested that spoilage could be prevented by heating the wine to a temperature high enough to kill the harmful microbes but low enough that it did not affect the flavor. Experimentation with heating wine for various times and temperatures revealed that, as Pasteur had predicted, the microorganisms could be killed without damaging the flavor of the wine. This became the foundation for the modern treatment of bottled liquids to prevent their spoilage, a process known as pasteurization.

Pasteurization was eventually used to treat milk. By 1900, pasteurized milk was commonly available, but raw milk was still more popular because the high-temperature pasteurization process used at the time left the milk with a cooked taste. In 1906, Milton J. Rosenau, director of the U.S. Marine Hospital Service's Hygienic Laboratory, in Staten Island, New York, established a low-temperature, slow pasteurization process (140°F for 20 minutes) that killed pathogens without changing the taste of the milk. This discovery eliminated the primary obstacle to public acceptance of pasteurized milk.

THE APPLICATION

Pasteurization had a major public health impact, particularly when applied to the milk industry. Between 1880 and 1907, 500 outbreaks of milk-borne diseases occurred in the United States. Milk from cows infected with *Brucella* bacteria caused brucellosis, or undulant fever, in humans. Brucellosis is a chronic debilitating disease characterized by intermittent fever, headache, joint pain, and weight loss. Contaminated milk also caused typhoid, scarlet fever, diphtheria, and tuberculosis. Pasteurization eliminated the pathogenic organisms that caused these diseases. More progress toward improving milk safety and recognizing safe levels of microbial content came when the Public Health Service created a document to assist Alabama in developing a statewide milk sanitation program. This publication ultimately evolved into the Grade A Pasteurized Milk Ordinance. This voluntary agreement established uniform sanitation standards for the interstate shipment of Grade A milk. It now is the basis of milk safety laws in all 50 states and Puerto Rico.[43,44]

Although pasteurization kills pathogenic bacteria and reduces the total number of microorganisms present, it allows many microbes to survive. Today, milk is graded on the basis of bacterial count. A maximum of 20,000 bacteria per milliliter is allowed in Grade A milk. The multiplication of the bacteria that remain eventually causes the milk to spoil. To prevent rapid multiplication after pasteurization, the milk must be cooled immediately and remain refrigerated. In addition to killing microorganisms, the heat also destroys enzymes in the milk; the inactivation of lipase extends the shelf life of homogenized milk by preventing it from becoming rancid. The inactivation of another enzyme called *phosphatase* is used to gauge the adequacy of pasteurization. Lack of phosphatase activity indicates that the heat treatment has been sufficient, but if phosphatase activity remains, it indicates that the milk was not treated adequately and may not be free of pathogens.

Today, almost all milk sold in the United States is pasteurized, and the same techniques are used to prevent spoilage in many other foods. Thanks to the work of Louis Pasteur and Milton J. Rosenau, we now enjoy the nutritional benefits of milk without the risk of infection with disease-causing organisms.

animals and to act as a neurotoxin in humans. Thus far, an association between dietary exposure to acrylamide and cancer in humans has not been consistently demonstrated.[45] Methods for reducing the amounts and potential toxicity of acrylamide in foods are being investigated.[46]

How Irradiation Preserves and Protects Food

Irradiation, also called *cold pasteurization*, exposes food to a high dose of X-rays, gamma radiation, or high-energy electrons to kill microorganisms and insects and inactivate enzymes that cause germination and ripening of fruits and vegetables. Irradiated foods must be labeled with the radura symbol shown in Figure 17.22A and the statement "Treated with radiation" or "Treated by irradiation"; however, foods that contain irradiated spices or other irradiated ingredients do not need to display this symbol.

irradiation A process, also called *cold pasteurization*, that exposes foods to radiation to kill contaminating organisms and retard ripening and spoilage of fruits and vegetables.

The FDA has approved irradiation to destroy pathogens in red meat and poultry and contaminants in spices; prevent insect infestation in flour and spices; increase the shelf life of potatoes; eliminate *Trichinella* in pork; control insects in fruits, vegetables, and grains; and slow the ripening and spoilage of some produce (Figure 17.22B).[47] Because irradiation produces unique compounds in irradiated foods, it is treated as a food additive, and the level of radiation that may be used is regulated. At the allowed levels of radiation, the amounts of these unique compounds produced are almost negligible and have not been found to be a risk to consumers. Irradiated foods may cost more because of the cost of the extra processing step, but in the future this may be offset by a longer shelf life. Irradiation should be used to complement, not replace, proper food handling by producers, processors, and consumers.

FIGURE 17.22 Food irradiation

A. This symbol is used to identify foods that have been treated with irradiation.

TREATED BY IRRADIATION

Cordelia Molloy/Photo Researchers, Inc.

B. After two weeks in cold storage, strawberries treated by irradiation remain free of mold (left), whereas untreated strawberries picked at the same time are covered with mold (right).

Food irradiation is used in more than 40 countries to treat everything from frogs' legs to rice, but it is used relatively infrequently in the United States. Part of the reason for this is lack of irradiation facilities, but public fear and suspicion of the technology also limit its use. The word "irradiation" fosters the belief that the food itself becomes radioactive. Opponents to food irradiation claim that it introduces carcinogens, depletes the nutritional value of food, and is used to allow the sale of previously contaminated foods. In fact, irradiated food is not radioactive, and scientific studies conducted over the past 50 years have found that the benefits of irradiation outweigh the potential risks.[47] It increases the safety and shelf life of foods and does not compromise nutritional quality, or noticeably change food texture, taste, or appearance as long as it is properly applied to a suitable product.[47] Irradiation can be used in place of chemical treatments, so it benefits consumers and the environment by reducing exposure to chemical pesticides and preservatives.

How Packaging Protects Food

Packaging plays an important role in food preservation: It keeps molds and bacteria out, keeps moisture in, and protects food from physical damage. An open package of cheddar cheese will grow mold in the refrigerator after only a few days. An unopened package will stay fresh for weeks.

Food packaging is continuously being improved. In the past two decades, for instance, consumer demand for fresh, easy-to-prepare foods has led manufacturers to offer partially cooked pasta, vegetables, seafood, fresh and cured meats, and dry products such as whole-bean and ground coffee in packaging that, if unopened, will keep perishable food fresh much longer than will conventional packaging. Vacuum packaging and **modified-atmosphere packaging (MAP)** use plastics or other packaging materials that are impermeable to oxygen. In vacuum packaging the air inside the package is removed prior to sealing in order to remove the oxygen. In modified atmosphere packaging the air is flushed out and replaced with a gas, such as carbon dioxide or nitrogen. In both types of packaging, the low oxygen level prevents the growth of aerobic bacteria, slows the ripening of fruits and vegetables, and slows down oxidation reactions, which cause discoloration in fruits and vegetables and rancidity in fats.

modified-atmosphere packaging (MAP) A preservation technique used to prolong the shelf life of processed or fresh food by changing the gases surrounding the food in the package.

MAP is often used to package cooked entrees such as pasta primavera or beef teriyaki. The raw ingredients are sealed in a plastic pouch, the air is flushed out, and the pouch and its contents are partially precooked and immediately refrigerated. This processing eliminates the need for the extreme cold of freezing or the extreme heat of canning, so flavor and nutrients are better preserved. Because these products are not heated to temperatures high enough to kill all bacteria and are not stored at temperatures low enough to prevent all bacteria from growing, they could pose a food safety risk. To ensure safety, fresh refrigerated foods should be purchased only from reputable vendors, used before the expiration date printed on the package, refrigerated until use, and heated according to the time and temperature directions on the package.

indirect food additive A substance that is expected to enter food unintentionally during manufacturing or from packaging. Indirect food additives are regulated by the FDA.

Packaging can protect food from spoilage, but even the best packaging can introduce risk if it becomes a part of the food. A variety of substances leach into foods from plastics, paper, and even dishes. One potential contaminant from plastics containers is bisphenol A (BPA). BPA is an industrial chemical that has been used since the 1960s to manufacture many hard plastic bottles (polycarbonate plastic) and the coating inside metal food and beverage cans (Figure 17.23). In 2003–2004, the National Health and Nutrition Examination Survey found detectable levels of BPA in 93% of urine samples from people ages 6 years and older, prompting concerns about the transfer of BPA to food and drinks.[48] However, based on the most recent safety assessment, the FDA has concluded that BPA is safe at the current levels occurring in foods. To protect infants and young children, who may be more vulnerable to BPA exposure, BPA-based materials are no longer used in baby bottles, sippy cups, and infant formula packaging.[49]

Alaska Stock Images/NG Image Collection

FIGURE 17.23 Does your water bottle contain bisphenol A?
To identify plastic containers containing BPA, look for those marked with recycle codes 3 or 7. Some, though not all, of these are made with BPA. To reduce BPA exposure, reduce your use of canned foods and don't microwave polycarbonate plastic food containers; over time, high temperatures may cause the polycarbonate to leach into the food.[48]

Substances such as BPA that unintentionally enter our food from sources such as packaging and food processing equipment are referred to as **indirect food additives** and the amounts and types are regulated by the FDA. However, these regulations apply only to the intended use of the product. When used improperly, additional packaging materials can migrate into food. These accidental contaminants are not regulated by the

FDA. It is the consumer's responsibility to prevent these substances from entering food. For instance, some plastics migrate into food when heated in a microwave oven. Thus, only packages designed for microwave cooking should be used.

George Semple

FIGURE 17.24 Additives are everywhere
The additives in these foods prevent the bread from molding, the fruit snacks from hardening, and the powdered sugar from clumping; they also smooth the texture of the pudding and give color and flavor to soft drinks and candy.

Food Additives

Food additives give margarine its yellow color, keep Parmesan cheese from clumping in the shaker, and prevent bread from molding (Figure 17.24). Substances that are intentionally added to foods are regulated by the FDA and are called **direct food additives**.

Food additives are used to make food safer; maintain palatability and wholesomeness; improve color, flavor, or texture; aid in processing; and enhance nutritional value (Table 17.8). Their use ensures the availability of wholesome, appetizing, and affordable foods that meet consumer demands throughout the year. The FDA's database "Everything Added to Food in the United States" lists more than 3000 additives.[50]

direct food additive A substance that is intentionally added to food. Direct food additives are regulated by the FDA.

preservative A compound that extends the shelf life of a product by retarding chemical, physical, or microbiological changes.

Additives That Prevent Spoilage Many substances are added to prevent bacteria and molds from causing food spoilage, to extend shelf life, or to protect the natural color and flavor of food. Sugar and salt are two of the oldest **preservatives**. They prevent microbial growth by decreasing the water availability in the product through osmosis; without adequate water, microbes cannot grow. For example, the high concentration of sugar in jams and jellies draws water away from the microbial cells and prevents them from growing. Antioxidants such as sulfites and BHT (butylated hydroxytoluene) are also used as preservatives. They prevent fats and oils in baked goods and other foods from becoming rancid or developing an off-flavor and prevent cut fruits such as apples from turning brown when exposed to air. Other preservatives act by blocking the natural ripening and enzymatic processes that continue to occur in foods even after harvest.

Additives to Improve Nutrient Content, Texture, Flavor, and Color Additives are not just used to make food safer and last longer. They are also used to enhance the nutrient content, texture, flavor, and color of foods.

Additives to Maintain or Improve Nutritional Quality Nutrients that are added to foods are considered additives. For example, refined grains are enriched with iron and some of the B vitamins that are lost in processing, milk is fortified with vitamin D, and calcium is added to everything from orange juice to breakfast cereal. Although the addition of these additives to foods benefits the population by increasing the nutrient content of the diet, it can also increase the risk of nutrient toxicities.

Additives to Improve and Maintain Texture Many different types of additives are used to enhance and maintain desired texture and consistency. Emulsifiers improve the homogeneity, stability, and uniformity of products such as ice cream. Stabilizers, thickeners, and texturizers, such as pectins and gums, are used to improve consistency or texture in pudding and to stabilize emulsions in foods such as salad dressing. Leavening agents are added to incorporate gas into breads and cakes, causing them to rise. Humectants, such as propylene glycol, cause moisture to be retained so products stay fresh. Anti-caking agents prevent crystalline products such as powdered sugar from absorbing moisture and caking or clumping.

Additives to Affect Flavor and Color Additives are also used to enhance the flavor and color of foods. For example, both natural and nonnutritive sweeteners are added to sweeten foods such as yogurt and fruit drinks. Color additives enhance the appearance of foods. A color additive is defined as any dye, pigment, or substance that can impart color when added or applied to a food, drug, cosmetic, or to the human body. Color additives are used in foods for many reasons, including to balance color loss due to storage or processing and to even out natural variations in food color. Color additives can be used to make foods appear more appetizing; however, they are not allowed to be used as deception to conceal inferiority.

Colors permitted for use in foods are classified as certified or exempt from certification. Certified food colors are synthetic dyes that have been tested to ensure safety, quality, consistency,

TABLE 17.8 Common Food Additives[51]

Type of additive	What's on the label	What they do	Where they are used
Preservatives	Ascorbic acid, citric acid, sodium benzoate, calcium propionate, sodium erythorbate, sodium nitrite, calcium sorbate, potassium sorbate, BHA, BHT, EDTA, tocopherols	Maintain freshness; prevent spoilage caused by bacteria, molds, fungi, or yeast; slow or prevent changes in color, flavor, or texture; delay rancidity	Jellies, beverages, baked goods, cured meats, oils and margarines, cereals, dressings, snack foods, fruits and vegetables
Sweeteners	Sucrose, glucose, fructose, sorbitol, mannitol, corn syrup, high-fructose corn syrup, saccharin, aspartame, sucralose, acesulfame potassium (acesulfame-K), neotame	Add sweetness with or without extra calories	Beverages, baked goods, table-top sweeteners, many processed foods
Color additives	FD&C Blue Nos. 1 and 2, FD&C Green No. 3, FD&C Red Nos. 3 and 40, FD&C Yellow Nos. 5 and 6, orange B, citrus red no. 2, annatto extract, β-carotene, grape skin extract, cochineal extract or carmine, paprika oleoresin, caramel color, fruit and vegetable juices, saffron, colorings or color added	Prevent color loss due to exposure to light, air, temperature extremes, and moisture; enhance colors; give color to colorless and "fun" foods	Processed foods, candies, snack foods, margarine, cheese, soft drinks, jellies, puddings and pie fillings
Flavors, spices, and flavor enhancers	Natural flavoring, artificial flavor, spices, monosodium glutamate (MSG), hydrolyzed soy protein, autolyzed yeast extract, disodium guanylate or inosinate	Add specific flavors or enhance flavors already present in foods	Many processed foods, puddings and pie fillings, gelatin mixes, cake mixes, salad dressings, candies, soft drinks, ice cream, BBQ sauce
Nutrients	Thiamine hydrochloride, riboflavin (vitamin B_2), niacin, niacinamide, folate or folic acid, β-carotene, potassium iodide, iron or ferrous sulfate, α-tocopherols, ascorbic acid, vitamin D, amino acids (L-tryptophan, L-lysine, L-leucine, L-methionine)	Replace vitamins and minerals lost in processing; add nutrients that may be lacking in the diet	Flour, breads, cereals, rice, pasta, margarine, salt, milk, fruit beverages, energy bars, breakfast drinks
Emulsifiers	Soy lecithin, mono- and diglycerides, egg yolks, polysorbates, sorbitan monostearate	Allow smooth mixing and prevent separation; reduce stickiness; control crystallization; keep ingredients dispersed	Salad dressings, peanut butter, chocolate, margarine, frozen desserts
Stabilizers and thickeners, binders, and texturizers	Gelatin, pectin, guar gum, carrageenan, xanthan gum, whey	Produce uniform texture, improve "mouth-feel"	Frozen desserts, dairy products, cakes, pudding and gelatin mixes, dressings, jams and jellies, sauces
pH control agents and acidulants	Lactic acid, citric acid, ammonium hydroxide, sodium carbonate	Control acidity and alkalinity, prevent spoilage	Beverages, frozen desserts, chocolate, low-acid canned foods, baking powder
Leavening agents	Baking soda, monocalcium phosphate, calcium carbonate	Promote rising of baked goods	Breads and other baked goods
Anti-caking agents	Calcium silicate, iron ammonium citrate, silicon dioxide	Keep powdered foods free-flowing, prevent moisture absorption	Salt, baking powder, confectioners' sugar
Humectants	Glycerin, sorbitol	Retain moisture	Shredded coconut, marshmallows, soft candies, confections

and strength of color. Nine certified color additives have been approved for use in the United States. Colors derived from plant, animal, and certain mineral sources are exempt from certification. They must still meet safety standards before they are approved for use in foods. Examples include annatto extract (yellow), dehydrated beets (bluish-red to brown), caramel (yellow to tan), β-carotene (yellow to orange), and grape skin extract (red, green).

Regulating Food Additives Food additives improve food quality and help protect us from disease, but if the wrong additive is used or if the wrong amount is added, it can do more harm than good. To prevent this, the federal Food, Drug, and Cosmetic (FD&C) Act of 1938 gave the FDA authority over food and food ingredients and defined requirements for truthful labeling of ingredients. This act provided exemptions and safe tolerance levels for additives that were necessary or unavoidable in production and established what are called **standards of identity**

standards of identity Regulations that define the allowable ingredients, composition, and other characteristics of foods.

© iStockphoto

OFF THE LABEL

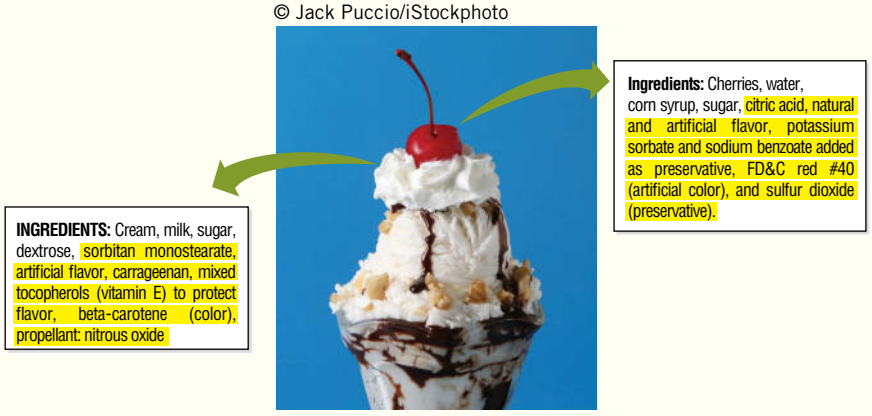
Are All Food Additives Safe for You?

Sometimes the ingredients listed on food labels sound like a chemical soup. Calcium propionate is added to bread, disodium EDTA is added to canned kidney beans, and BHA is in potato chips. Most of us ignore this list of chemicals, and for most of us that is fine, because these additives cause no problems. The FDA does not approve food additives unless they are safe for most consumers, but this doesn't mean they are safe for everyone.

For individuals who are sensitive to certain additives, such as preservatives or colors, the ingredient list provides information that can be lifesaving. For example, in sensitive individuals, sulfites can cause symptoms that range from a stomachache and hives to severe asthmatic reactions. Sulfite sensitivity is most common in individuals with asthma; consuming sulfites causes symptoms in up to 10% of people with asthma.[52] Sulfites are used to preserve foods such as baked goods, canned vegetables, condiments, and maraschino cherries. Sensitive individuals can identify foods that contain sulfites by checking food labels. The forms of sulfites allowed in packaged foods include sulfur dioxide, sodium sulfite, sodium and potassium bisulfite, and sodium and potassium metabisulfite. Foods served in restaurants are also a concern because sulfites are sometimes used in food preparation. For example, a potato dish on the menu may be prepared using potatoes that were peeled and soaked in a sulfite solution before cooking.

Food colors can also cause reactions in sensitive individuals. The color additive FD&C Yellow No. 5, which is listed as tartrazine on medicine labels, may cause itching and hives in sensitive people. It is found in beverages, desserts, and processed vegetables. Sensitivity to FD&C Yellow No. 5 is rare.[53] Those who are sensitive can avoid products containing this color additive because all foods that contain FDA-certified color additives must list them by name in the ingredient list. Colors that are exempt from certification, such as dehydrated beets and carotenoids, do not have to be specifically identified and may be listed on the label collectively as "artificial color" (see figure).[54]

© Jack Puccio/iStockphoto



Additives add color and flavor to many foods but can be hazardous to individuals sensitive to them.

for certain foods. Standards of identity define exactly the ingredients that can be contained in certain foods such as mayonnaise, jelly, and orange juice. The FD&C Act also gave the FDA the responsibility of testing food additives for safety. Because the FDA could not possibly test all additives, the 1958 Food Additives Amendment transferred the responsibility for testing from the FDA to the manufacturer. Today, when a manufacturer wants to use a new food additive, a petition must be submitted to the FDA. The petition describes the chemical composition of the additive, how it is manufactured, and how it is detected and measured in food. The manufacturer must prove that the additive will be effective for its intended purpose at the proposed levels, that it is safe for its intended use, and that its use is necessary. Additives may not be used to disguise inferior products or deceive consumers. They cannot be used if they significantly destroy nutrients or where the same effect can be achieved by sound manufacturing processes.

The safety of food additives is of primary concern. Substances that are toxic at some level of consumption may be harmless at a lower level. To ensure that additives are safe, most of those that are allowed in foods can be added only at levels 100 times below the highest level that has been shown to have no harmful effects (see **Off the Label: Are All Food Additives Safe for You?**).

This is a greater margin of safety than exists for many vitamins and other naturally occurring substances.

The regulations for substances that cause cancer are far more rigid because of the **Delaney Clause**, part of the 1958 Food Additives Amendment. It states that a substance that induces cancer in either an animal species or humans, at any dosage, may not be added to food. Debate continues regarding whether the Delaney Clause should be liberalized to allow the use of substances that are added at a level so low that they would not represent a significant health risk.

Delaney Clause A clause added to the 1958 Food Additives Amendment of the Pure Food and Drug Act that prohibits the intentional addition to foods of any compound that has been shown to induce cancer in animals or humans at any dose.

prior-sanctioned substances Refers to substances that the FDA or the USDA had determined were safe for use in a specific food prior to the 1958 Food Additives Amendment.

nitrosamines Carcinogenic compounds produced by reactions between nitrites and amino acids.

generally recognized as safe (GRAS) A group of chemical additives that are generally recognized as safe based on their long-standing presence in the food supply without obvious harmful effects.

Additives Used Before 1958

When the 1958 Food Additives Amendment was passed, over 600 chemicals defined as food additives were already in common use. To accommodate these substances, the amendment exempted two groups of substances from the food additive regulation process. One group included substances that the FDA or the USDA had determined were safe; these were designated as **prior-sanctioned substances**. The nitrates and nitrites used to retard the growth of *Clostridium botulinum* in cured meats such as ham and hot dogs are on the prior-sanctioned list. However, the use of these has been controversial because they form carcinogenic **nitrosamines** in the digestive tract. They are still allowed in foods because there is little evidence that they pose a serious risk in the amounts consumed in the human diet.[55] To minimize any risk posed by nitrosamines without increasing the risk of bacterial illness, the FDA has limited the amount of nitrate and nitrite that can be added to food and has required the addition of antioxidants, which reduce nitrosamine formation, to foods containing these additives. Consumers can reduce nitrosamine exposure by limiting cured meat consumption to 3 to 4 oz/week and maintaining adequate intakes of the antioxidant vitamins C and E.

A second category of substances excluded from the food additive regulation process is **generally recognized as safe (GRAS)** substances. GRAS substances are those whose use is generally recognized as safe, based on their extensive history of use in food before 1958 or based on published scientific evidence.

Just because a substance is on the prior-sanctioned or GRAS list doesn't mean it is safe or that it will stay on these lists. If new evidence emerges that suggests that a substance in either of these categories is unsafe, the FDA may take action to remove the substance from food products.

OUTCOME

How could homemade frozen custard, which sounds so wholesome, make so many people sick? The frozen custard that the fourth graders made contained raw eggs, which sometimes harbor the bacterium *Salmonella enteritidis.* Thoroughly cooking eggs kills the bacteria, but any food that contains uncooked eggs is a risk. Since the ingredients for all the frozen custard were mixed as one large batch, bacteria from even a single infected egg could have contaminated the entire recipe. The low temperatures used for making frozen custard would retard bacterial growth but not kill the organisms. The fourth graders were slow in measuring and mixing ingredients, so the mixture of raw eggs, milk, sugar, and cream sat at room temperature for almost an hour before it was chilled and placed in the ice cream maker, allowing the bacteria to multiply. When the inspectors sampled the frozen custard, they found it contained large numbers of *Salmonella*. Tracking the ingredients used to make the frozen custard revealed that the school had purchased the eggs from a distributor in Florida, who had bought them from a farm in Maryland. At next year's celebration the school decided to have homemade ice cream, which is not made with raw eggs. **Fortunately, all of the individuals who became ill recovered, but *Salmonella* infection can cause serious illness and even death in elderly people, infants, and persons with impaired immune function.**

SUMMARY

17.1 How Can Food Make Us Sick?

- Food-borne illness is any illness that is related to the consumption of food or contaminants or toxins in food.
- Food may become contaminated where it is grown or produced, during processing or storage, or even in the home. Once contaminated, food preparation utensils and surfaces can cross-contaminate other foods.
- The harm caused by contaminants in the food supply depends on the type of toxin, the dose, the length of time over which it is consumed, and the size and health status of the consumer.

17.2 Keeping Food Safe

- The safety of the food supply is monitored by agencies at the international, federal, state, and local levels. The government promotes the use of HACCP (Hazard Analysis Critical Control Point) principles to ensure food safety. HACCP systems help prevent or eliminate food contamination and track contaminated foods to prevent food-borne illness.
- It is the job of the food manufacturer to label food products properly and establish and implement a HACCP system for its particular business.
- Consumers play an important role in limiting the risks of developing food-borne illness through the way they store, handle, and prepare food.

17.3 Pathogens in Food

- The pathogens that most often affect the food supply include bacteria, viruses, molds, and parasites. Some bacteria cause food-borne infection because they are able to grow in the gastrointestinal tract when ingested. Others produce toxins in food, and consumption of the toxin causes food-borne intoxication.
- Viruses do not grow on food, but when consumed in food, they can enter human cells where they can reproduce and cause food-borne illness.
- Molds that grow on foods produce toxins that can harm consumers.
- Parasites include microscopic single-celled animals as well as worms that can be seen with the naked eye. They are consumed in contaminated water or food.
- Improperly folded prion proteins cause bovine spongiform encephalopathy (BSE) in cattle. The risk of acquiring the human form of this deadly degenerative neurological disease is extremely low.

17.4 How to Reduce the Risk of Microbial Food-Borne Illness

- The risk of food-borne illness can be decreased through proper food selection, storage, preparation, and cooking.
- Food should be refrigerated or frozen to slow or stop microbial growth and cooked to recommended temperatures to kill pathogens. Food should not be held between 40° and 140°F because this temperature range favors bacterial growth.
- Foods should be handled carefully to avoid cross-contamination.
- Cooked foods should be heated to temperatures that kill pathogens.
- The principles of food safety should also be applied when choosing foods away from home.

17.5 Agricultural and Industrial Chemicals in Food

- Contaminants such as pesticides applied to crops and industrial wastes that leach into water may find their way into the food supply. To decrease the potential risk of pesticides, safer ones are being developed and U.S. farmers are reducing the amounts applied by using integrated pest management and organic methods.
- Antibiotics are given to animals to prevent disease and increase growth. The widespread use of these drugs contributes to the emergence of antibiotic-resistant strains of bacteria. Changes are being made to limit the use of antibiotics in food animals.
- Industrial pollutants such as PCBs, radioactive substances, and toxic metals have contaminated some waterways and the fish that live in them. As these contaminants move through the food chain, their concentrations increase.
- Consumers can reduce the amounts of pesticides and other environmental contaminants in food by careful selection and handling of produce; selection of low-fat saltwater varieties of fish caught well offshore in unpolluted waters; and trimming fat from meat, poultry, and fish before cooking.

17.6 Technology for Keeping Food Safe

- High and low temperatures are used to prevent food spoilage. High temperatures used in canning, pasteurization, sterilization, and cooking kill microorganisms. However, cooking can also introduce hazardous substances such as polycyclic aromatic hydrocarbons, heterocyclic amines, and acrylamide. Cold temperatures slow or prevent microbial growth.
- Irradiation preserves food by exposing it to X-rays, gamma radiation, or high-energy electrons. It kills microorganisms, destroys insects, and slows the germination and ripening of fruits and vegetables.
- Packaging can help preserve food, but can introduce risk if it leaches into the food. Modified atmosphere packaging (MAP) reduces the oxygen available for microbial growth.
- Food additives include all substances that can reasonably be expected to find their way into a food during processing. This includes direct food additives, which are used to preserve or enhance the appeal of food, and indirect food additives, which are substances known to find their way into food during cooking, processing, and packaging. Direct and indirect food additives are regulated by the FDA. Accidental contaminants, which enter food when it is used or prepared incorrectly, are not regulated by the FDA.

FOCUS ON Biotechnology

© kkgas/iStockphoto

CHAPTER OUTLINE

FOCUS 5.1 **How Does Biotechnology Work?**

Genetics: From Genes to Traits

Methods of Biotechnology

Is Genetic Modification Really New?

FOCUS 5.2 **Applications of Modern Biotechnology**

How Biotechnology Can Increase Crop Yields

How Biotechnology Can Improve Nutritional Quality

How Biotechnology Impacts Food Quality and Processing

How Biotechnology Is Used in Animal Food Production

How Biotechnology Is Used to Combat Disease

FOCUS 5.3 **Safety and Regulation of Genetically Modified Foods**

Consumer Safety

Environmental Concerns

Regulation of Genetically Engineered Food Products

DEA / G. NIMATALLAH/Getty Images, Inc.

FIGURE F5.1 Chimera
Boyer and Cohen called the small loops of bacterial DNA that contain DNA from another organism *chimeras*, after a mythical fire-breathing beast that is a mixture of a lion, a goat, and a serpent.

In 1909, British physician Archibald Garrod hypothesized that genes might be involved in creating proteins. By 1966, investigators had deciphered the genetic code, which links the information in DNA to the synthesis of proteins. The proteins made affect the traits that an organism exhibits. Then, in 1972, a discussion between Dr. Stanley Cohen of Stanford University and Dr. Herbert Boyer of the University of California at San Francisco led to the birth of genetic engineering. They brought together the information needed to allow genetic instructions from one organism to be inserted into another. Cohen's laboratory had been studying how bacterial cells take up small loops of DNA. Boyer had been studying enzymes that could cut DNA at specific locations and paste it back together again. Cohen and Boyer realized that fragments of DNA could be introduced into bacterial cells using the procedure developed in Cohen's lab (Figure F5.1). As the bacteria multiplied, so would the new piece of DNA—making copies, or clones. **These techniques for recombining DNA from different sources and cloning it are the basis for all genetic engineering.**[1]

F5.1 How Does Biotechnology Work?

LEARNING OBJECTIVES

- Explain how genetic engineering introduces new traits into plants.
- Compare and contrast traditional breeding methods and modern biotechnology.

Modern **biotechnology** is possible because of the emergence of techniques that allow scientists to alter the DNA of plants, animals, yeast, and bacteria. By modifying DNA, these techniques, referred to as **genetic engineering**, allow scientists to change the proteins that a cell or organism can make, introducing new traits, enhancing desirable ones, or eliminating undesirable ones. Genetic engineering often involves taking the gene for a desired trait from one organism and transferring it to another. It has allowed researchers to create bacteria that make medicines for humans, plants that are disease resistant, and foods that provide a healthier mix of nutrients. As this new technology has evolved, so has the vocabulary to describe it (Table F5.1). Genetically modified (GM) plants and other organisms produced using these techniques are often referred to as *genetically modified organisms* or *GMOs*.

biotechnology The process of manipulating life forms via genetic engineering in order to provide desirable products for human use.

genetic engineering A set of techniques used to manipulate DNA for the purpose of changing the characteristics of an organism or creating a new product.

Genetics: From Genes to Traits

The characteristics of a plant or animal are carried in its genes. These genes, which are segments of DNA, are passed from generation to generation. Genes contain the information that directs the synthesis of proteins. The specific proteins that are made then determine the traits that an individual organism displays.

DNA Structure DNA is a long, threadlike molecule consisting of two strands that twist around each other, forming a double helix. Each strand has a backbone made up of alternating units of the five-carbon sugar deoxyribose and phosphate groups. Each deoxyribose

TABLE F5.1 Terms Used in Genetic Engineering

Bioengineered foods	Foods that have been produced using biotechnology.
Biotechnology	Manipulating life forms via genetic engineering to provide desirable products for human use.
Chimera	A DNA molecule composed of DNA from two different species, or an organism consisting of tissues of diverse genetic constitution.
Cloning	Producing an exact duplicate of a gene or an organism.
DNA	A long, thread-like molecule that carries the genetic information of an organism.
Gene	A unit of DNA that provides the coded instructions for the synthesis of RNA, which when translated into a protein, leads to the expression of a hereditary trait. It is the physical basis for the transmission of the characteristics of living organisms from one generation to another.
Gene splicing	The precise joining of DNA from different sources to create a new gene structure.
Genetic engineering	Technology used to selectively alter genes. It can be used to manipulate the genetic material of an organism in such a way as to allow it to produce new and different types of proteins. Other terms applicable to the same techniques are *gene splicing*, *gene manipulation*, *genetic modification*, or *recombinant DNA technology.*
Genome	The total complement of genetic information in an organism.
GM crops	Genetically modified crops.
GMO	Genetically modified organism.
Hybridization	The mating of different plants to enhance favorable characteristics.
Plasmid	An independent, stable, self-replicating piece of circular DNA in bacterial cells. It is not a part of the normal cell genome.
Recombinant DNA	DNA that has been formed by joining the DNA from different sources.
Transgenic organism	An organism with a gene or group of genes intentionally transferred from another species or breed.

sugar is attached to a molecule called a *base*. The four different bases that occur in DNA—adenine, thymine, cytosine, and guanine—are usually abbreviated as A, T, C, and G, respectively. The bases on adjacent strands bind to one another, connecting the two strands. Each base binds only to its complementary base: adenine to thymine and cytosine to guanine (Figure F5.2).

The DNA of all organisms—plants, bacteria, and animals, including humans—is made up of the same DNA bases. The differences in the sequence of bases in DNA are responsible for the genetic differences among living things, whether they are differences between species or differences between individuals of the same species. Different individuals of the same species have small differences in the base sequence of their DNA; only identical twins share the same base sequence. Organisms of different species, such as humans and corn plants, have larger differences in the sequences of DNA bases.

Genes to Proteins to Traits The sequence of bases present in a gene specifies the sequence of amino acids that will be present in a protein (see Chapter 6). In the genetic code, three bases code for a single amino acid. The same three bases always code for the same amino acid; for example, the DNA base sequence ACC corresponds to the amino acid tryptophan. Because the code is universal among all life on Earth, a particular three-base sequence codes for the same amino acid whether it is in a bacterium, a mosquito, a corn plant, or a human being.

When a gene is expressed, the protein it codes for is made, providing certain characteristics to the organism. For example, if a protein that stimulates growth is made, the organism will grow bigger or faster, and if a protein pigment is made, it will affect the color of the plant or animal. The presence or absence of specific proteins determines the traits that an individual organism displays (Figure F5.3).

Even though organisms of different species are very different, they may have genes with similar base sequences if they both need to make the same protein. For example, humans and pigs both rely on the protein hemoglobin to carry oxygen in the blood, so both humans and pigs have a gene with a very similar sequence of bases that codes for the protein hemoglobin. It is

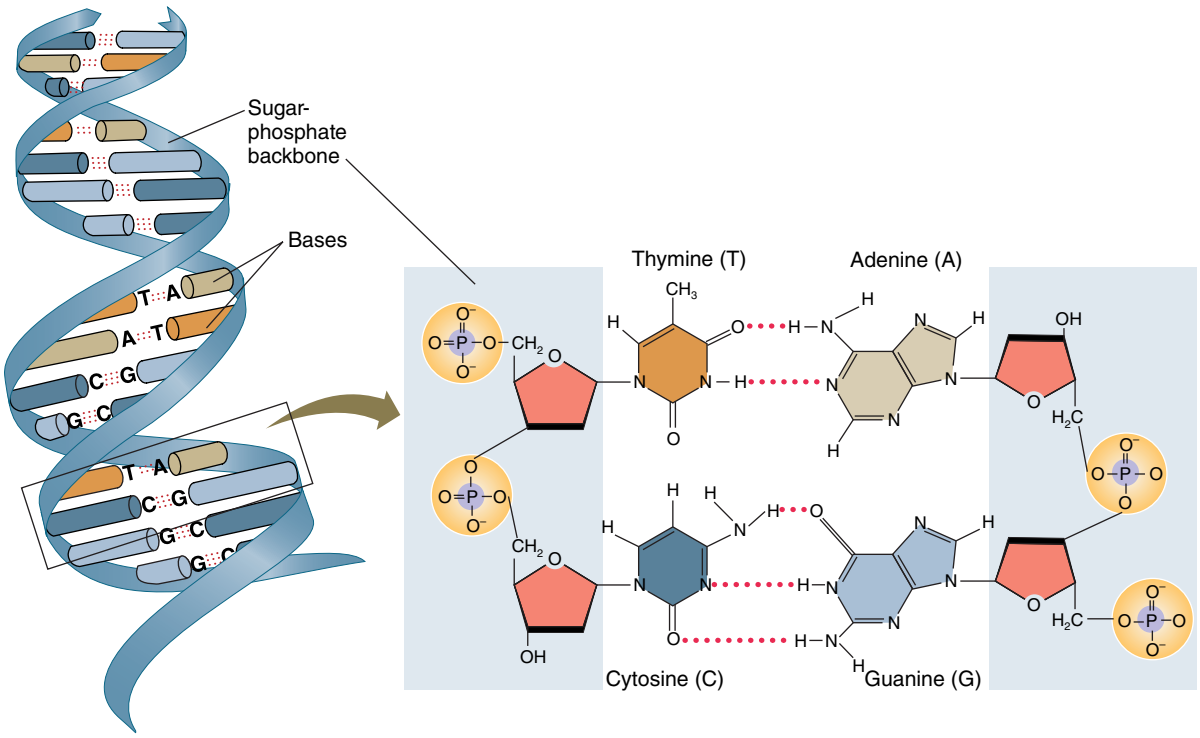


FIGURE F5.2 DNA: the double helix
DNA is a double-stranded helical molecule. Each strand has a backbone made up of phosphate groups and sugar molecules. Each sugar is attached to adenine (A), thymine (T), cytosine (C), or guanine (G). The two strands of the DNA molecule are bonded together by these bases: A bonds to T, and C bonds to G.

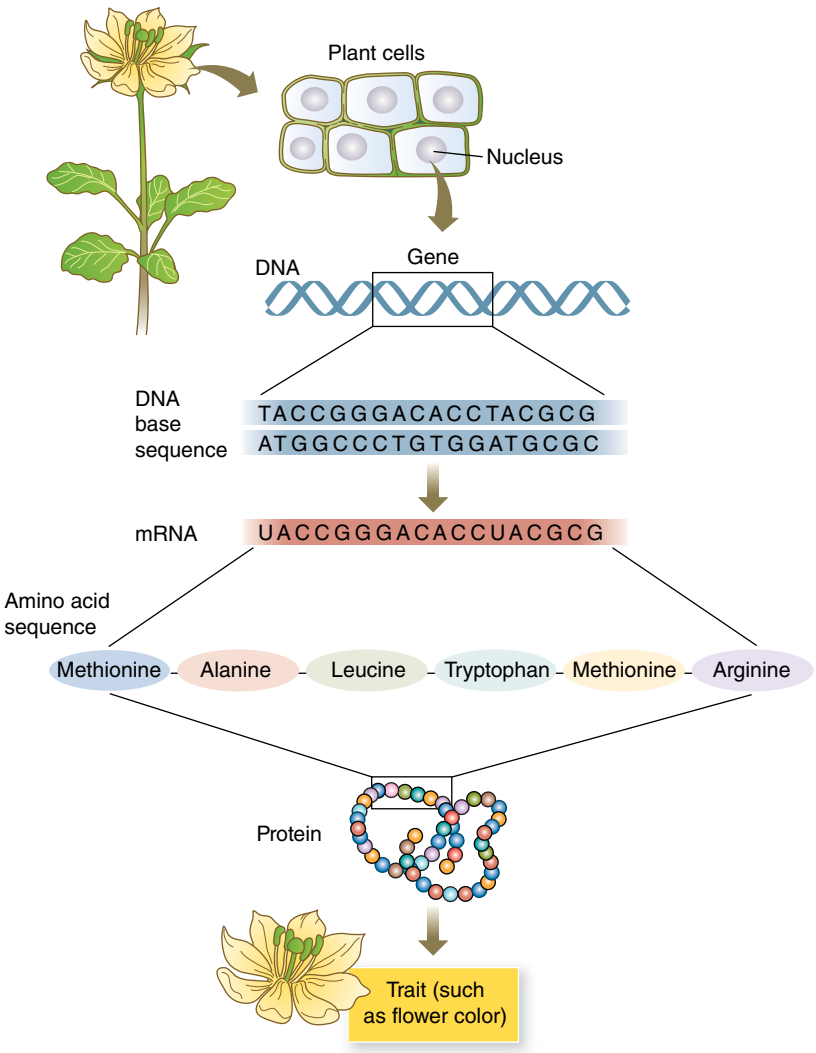


FIGURE F5.3 Relationships among genes, proteins, and traits
The DNA base sequence in a gene codes for the sequence of amino acids that are joined to form the polypeptide chain of a protein. Which proteins are made determines an organism's traits.

estimated that 25% of the genes found in plants are also present in humans, presumably because they code for proteins needed by both organisms.[2]

Passing Traits from Parent to Offspring When an organism reproduces, it passes its genes—and thus the instructions to make the proteins coded for by these genes—to the next generation. When two organisms breed, some genes from each are passed to the offspring. The result is a new combination of genes and the traits for which they code. Over time, mutations can occur in the sequence of bases that make up the genes. Some of these mutations are harmful, reducing the organism's ability to survive and reproduce. When an organism does not reproduce, it does not pass these harmful mutations on to the next generation. Other mutations are beneficial and result in traits that allow the organism to survive more easily and thus to reproduce and pass on the altered genes. Over millions of years, many genes have been changed by mutations, and those that code for beneficial traits have been passed on because the organisms carrying them thrive and reproduce. The idea behind biotechnology is to speed up the process of introducing beneficial traits that can then be passed from generation to generation.

Methods of Biotechnology

The first step in genetic modification is to identify a stretch of DNA, or gene, for a desired trait, such as resistance to a particular disease. This gene of interest can be from a plant, animal, or

Stanley N. Cohen/Photo Researchers

FIGURE F5.4 Bacterial plasmid
This electron micrograph shows a plasmid, which is a small loop of DNA found in bacterial cells.

bacterial cell. The gene is then clipped out with the specific DNA-cutting enzymes studied by Dr. Boyer, which are called **restriction enzymes** (see Chapter 6, *Science Applied: How Bacteria Created the Field of Biotechnology*).

A number of different techniques can be used to introduce the gene into the host cell. If the host cell is a plant cell, the gene can be pasted into, or recombined with, the small loops of bacterial DNA studied by Dr. Cohen, called **plasmids** (Figure F5.4). Plasmids have the ability to carry genes from one place to another. The plasmid containing the gene of interest can be taken up by a bacterial cell. The bacterial cell can then transfer the gene to a plant cell. Once inside the plant cell, the new DNA migrates to the nucleus, where the gene for the new trait can be integrated into the plant's DNA. The DNA is then referred to as **recombinant DNA** because the DNA from the plasmid has been combined with the plant's DNA (Figure F5.5).

A second method used to get genes into plant cells involves painting the desired segment of DNA onto microscopic metal particles. These are then loaded into a "gene gun" and shot into the plant cells. Once inside the cells, the DNA is washed off the metal particles by cellular fluids and migrates to the nucleus, where it is incorporated into the plant's DNA, forming recombinant DNA.

restriction enzyme A bacterial enzyme used in genetic engineering that has the ability to cut DNA in a specific location.

plasmid A loop of bacterial DNA that is independent of the bacterial chromosome.

recombinant DNA DNA that has been formed by joining DNA from different sources.

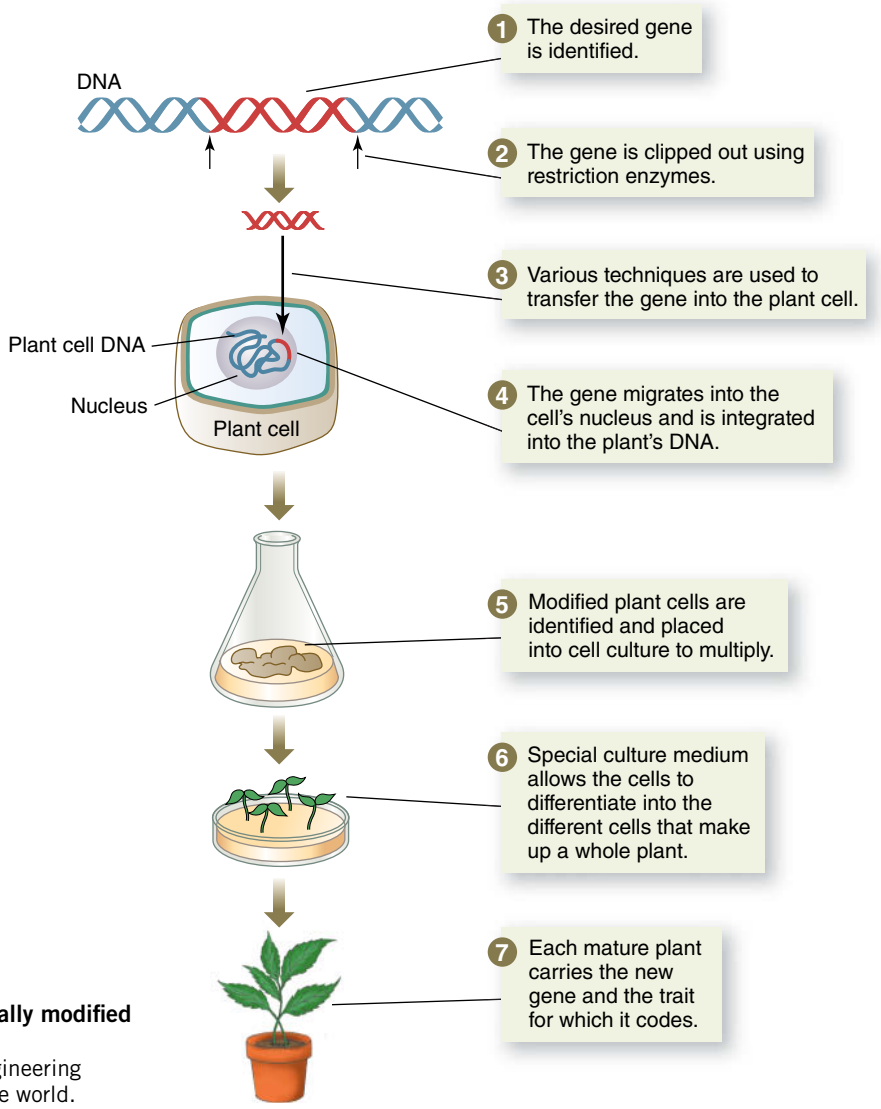


FIGURE F5.5 Engineering genetically modified plants
Crops developed using the genetic engineering steps shown here are grown all over the world.

The modified plant cells produced by either technique are then allowed to multiply. As they do, the new gene is reproduced with them. The cells are then allowed to divide into more and more cells and eventually differentiate into the various types of cells that make up a whole plant. The new plant is a **transgenic organism**. Each cell in the new plant contains the transferred gene for the desired trait, such as disease resistance (see Figure F5.5).

transgenic organism An organism with a gene or group of genes intentionally transferred from another species or breed.

Modifying the genes of animals is more difficult because animal cells do not take up genes as easily as plant cells do, and making copies of these cells (clones) is also more challenging. Despite this, genetic engineering has been used to produce cows that yield more milk, cattle and pigs with more meat on them, and sheep that grow more wool.[3]

Is Genetic Modification Really New?

Modern genetic engineering technology is new, but humans have been directing the genetic modification of plants and animals for about 10,000 years. Farmers thousands of years ago didn't use gene guns or bacterial plasmids, but they selected seeds from plants with the most desirable characteristics to plant for the next year's crop, bred the animals that grew fastest or produced the most milk to improve the productivity of the next generation, and cross-bred plant varieties to combine the desired traits of each. Almost every fruit, vegetable, or crop grown today has been in some way genetically modified using traditional **selective breeding** techniques. Some of these crops, such as pumpkins, potatoes, sugar beets, and varieties of corn, oats, and rice, would not have developed without human intervention. These interventions have allowed modern farmers to grow plants that produce more food that is more nutritious and can better withstand harsh environments and resist disease.

selective breeding Techniques to selectively control mating in plants and animals for the purpose of producing organisms that better serve human needs.

Traditional Breeding Technology Traditional breeding begins when farmers and ranchers select plants or animals with desired characteristics, such as high yield, better flavor, longer shelf life, or resistance to disease and insects. The traits can then be brought together by controlled mating. Plant breeders use a process called **hybridization**, in which two related plants are cross-pollinated or cross-fertilized (Figure F5.6). The resulting offspring has characteristics from both parent plants. For example, a breeder who wanted to produce a variety of wheat that was high yielding and resistant to cool temperatures would cross plants with these two traits. The breeder would then select the offspring that acquired both of the desired traits.

hybridization The process of cross-fertilizing two related plants with the goal of producing an offspring that has the desirable characteristics of both parent plants.

Cross-breeding of animals has a similar goal. Animal breeders use both inbreeding and outbreeding. Inbreeding involves crosses between closely related animals. This type of breeding can intensify desirable traits but may also intensify undesirable traits. Outbreeding crosses unrelated animals to reduce undesirable traits, increase variability, and introduce new traits. Today, inbreeding and outbreeding are carried out by artificial insemination.

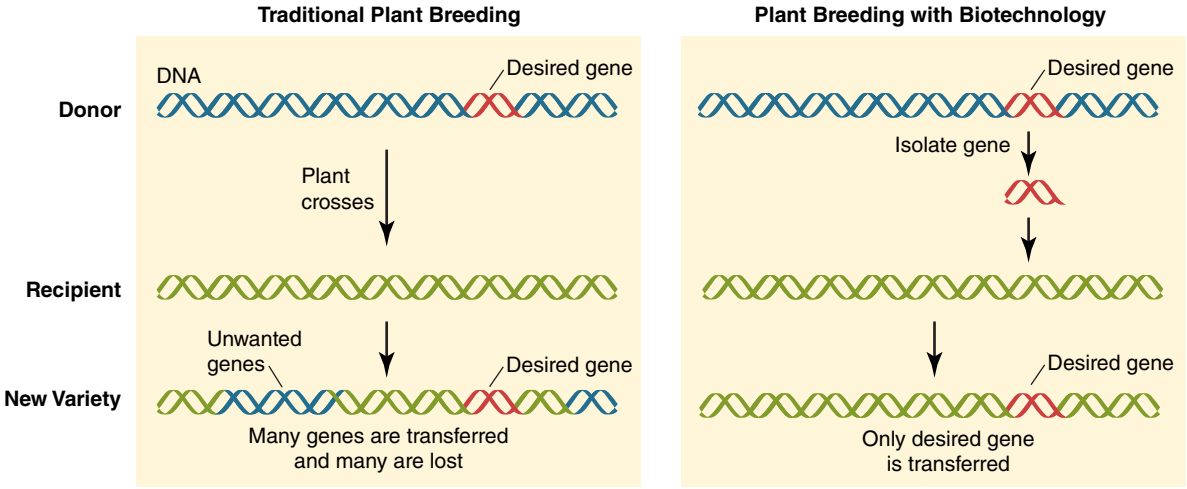
Advantages of Modern Biotechnology Traditional breeding techniques work well, but they have limitations in terms of both time and outcome. Breeding generations of plants or animals to consistently produce a desired trait is time consuming; a new trait can only be produced once in the reproductive cycle of the plant or animal. Only plants or animals of the same or closely related species can be interbred. Not every offspring will inherit the desirable traits. Because cross-breeding transfers a set of genes from the parents to the offspring, both desirable and undesirable traits are transferred. Eliminating the undesirable genes while keeping the desirable ones can require many crosses.

Biotechnology, which selects specific genes in the laboratory, has significantly sped up this process and removed certain limitations. It enables breeders to select, modify, and transfer single genes. This speeds up the process by reducing the time and cost of breeding the crosses that are needed to select out the undesirable traits (Figure F5.7). In addition, biotechnology is not limited by whether two animals are capable of cross-breeding but, rather, can select desirable genes from any species, since the way DNA codes for proteins in plants, animals, yeast, and bacteria is the same. This allows traits from different species and completely unrelated organisms to be used.

David Woodfall/Stone/Getty Images, Inc.

FIGURE F5.6 Hybridization
Cross-pollination or cross-fertilization, as illustrated with these oat seedlings, is a traditional method for breeding new plant varieties.

FIGURE F5.7 Traditional plant breeding versus biotechnology



A. When traditional plant-breeding methods are used, thousands of genes from each plant are mixed. Only a few of the new varieties that result contain the desired gene, and those that do may also contain unwanted genes. It can take many attempts over many years to remove the unwanted traits while retaining the desired ones.

B. Genetic engineering is more precise, more predictable, and faster. It allows the insertion of one or two genes into a plant without the transfer of genes coding for undesirable traits.

F5.2 Applications of Modern Biotechnology

LEARNING OBJECTIVES

- Discuss how genetic engineering is used to increase crop yields.
- Describe how GMOs are used to improve nutrient intake.
- Explain how genetic engineering can be used to combat human disease.

The techniques of biotechnology can be used in a variety of ways in both production and processing to alter the quantity, quality, cost, safety, and shelf life of the food supply (Table F5.2). This technology also has great potential for addressing the problem of world hunger and malnutrition.

TABLE F5.2 Examples of Characteristics Introduced Using Genetic Engineering

Food	Characteristic
Cherry tomato	Better taste, color, texture
Plums	Virus resistance
Canola oil	Altered fatty acid composition
Tomato	Thicker skin, altered pectin content
Corn	Insect resistance herbicide resistance
Cotton	Insect resistance herbicide resistance
Squash	Virus resistance
Papaya	Virus resistance
Potatoes	Potato beetle resistance, virus resistance
Soybeans	Herbicide resistance, high oleic acid content to reduce need for hydrogenation
Sugar beets	Herbicide resistance
Sunflower	High oleic acid content to reduce need for hydrogenation

How Biotechnology Can Increase Crop Yields

Genetic modification of crops can increase yields either directly, by inserting genes that improve the efficiency with which plants convert sunlight into food, or indirectly, by creating plants that are resistant to herbicides, insect pests, and plant diseases, thus reducing crop losses. Scientists are also working to develop plants that can withstand drought, freezing, and high salt concentrations. Many attempts in the last century to increase crop yields in developing countries have failed because they required expensive machinery and chemicals. With genetically engineered crops, simply providing a new type of seed has the potential to increase food production.

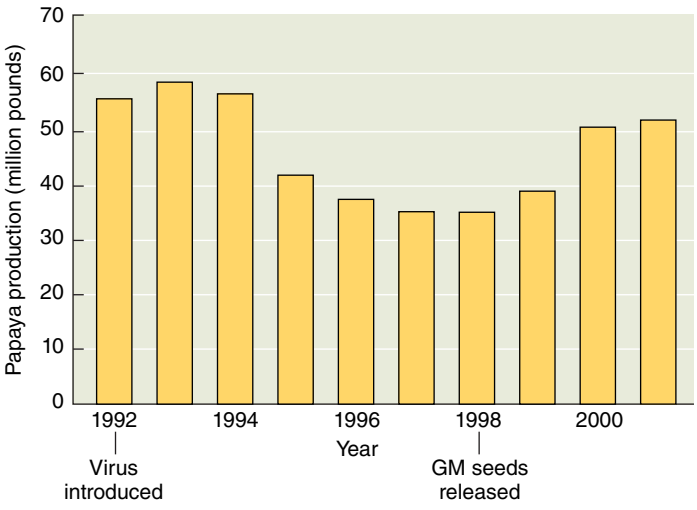
Scott Camazine/Photo Researchers/Getty Images, Inc.

FIGURE F5.8 Bt corn
Genetically engineered corn that produces the Bt protein is toxic to this European corn borer.

Herbicide Resistance Herbicides are chemical pesticides that are sprayed on crops in the field to control weeds. Effective herbicides kill weeds but do not harm crops. A crop such as soybeans is not harmed by a particular herbicide because it contains enzymes that inactivate the herbicide. These enzymes are crop specific, so only certain herbicides can be used with certain crops. In some cases the weeds and the crops are resistant to the same herbicide, so the farmer has few or no choices for weed control. Genetic engineering allows researchers to transfer genes for herbicide resistance to plants, making them resistant to new types of herbicides. Farmers then have more options for weed control so they can use herbicides that are less expensive, more effective, and less environmentally damaging.

Insect Resistance Genetic engineering techniques can increase insect resistance in plants. For example, a gene from the bacterium *Bacillus thuringiensis* produces a protein that is toxic to certain insects but safe for humans and other animals. By inserting the gene for this protein into plant cells, scientists have created plants that manufacture their own insecticide. The protein produced by this gene, known as Bt, has been used as an insecticide for over 30 years. But when plants manufacture their own insecticide, Bt does not need to be sprayed on the plants. This saves the farmer money, fuel, and time. It also benefits the environment because the Bt affects only insects feeding on the crop of interest and is not spread to surrounding foliage. Corn, potatoes, and cotton have been genetically modified to produce the Bt protein (Figure F5.8). It is estimated that the use of genetically modified (GM) crops has reduced pesticide (herbicides plus insecticides) use by 553 million kilograms since 1996 (an 8.6% reduction).[4]

Disease Resistance Potato, squash, cucumber, watermelon, plums, and papaya have been modified to resist viral infections. The benefits of this technology are illustrated by how it helped to preserve Hawaii's papaya crop. In the mid-1990s the papaya ring-spot virus threatened to wipe out Hawaii's second largest crop. Traditional plant breeding was not able to produce a virus-resistant strain of papaya, but by inserting a gene that acted like a vaccine into the papaya plant DNA, scientists were able to produce papaya plants that were immune to the virus (Figure F5.9).[5]



© Alberto Pomares/iStockphoto

FIGURE F5.9 Virus-resistant papaya
Seeds for papaya that are resistant to the papaya ring-spot virus were released for commercialization in 1998, allowing Hawaiian papaya production to rebound. This was the first genetically enhanced fruit crop on the market.

How Biotechnology Can Improve Nutritional Quality

Although the causes of malnutrition are rooted in political, economic, and cultural issues that cannot be resolved by agricultural technology alone, genetically modified crops that target some of the major nutritional deficiencies worldwide are being developed.

To address protein deficiency, varieties of sorghum and cassava with higher levels of essential amino acids are being created.[6] To address iron deficiency, rice has been engineered to contain more iron.[7] To address vitamin A deficiency, genes that code for the production of enzymes needed for the synthesis of the vitamin A precursor β-carotene have been inserted into rice, which is a dietary staple for half the world's population (Figure F5.10).[8] This GM rice, called *Golden Rice*, will not become broadly available until it is acceptable to farmers and consumers, deemed safe and approved by national regulatory agencies, and shown to improve vitamin A status in the population (see Chapter 9, *Debate: Combating Vitamin A Deficiency with Golden Rice*).[9–11] New varieties of cassava, which is a dietary staple for over 250 million people in Sub-Saharan Africa, are also being developed. The BioCassava Plus program is using biotechnology to create two types of cassava: one for West Africa that will have higher levels of both β-carotene and iron, and a second variety targeting East Africa that combines disease resistance with higher levels of β-carotene.[12]

Golden Rice Humanitarian Board. www.goldenrice.org

FIGURE F5.10 Golden Rice
The white rice shown on the left does not contain the vitamin A precursor β-carotene. The rice shown on the right, called *Golden Rice*, has been genetically modified to produce β-carotene, which gives it a yellow-orange color.

Rosenfeld Images Ltd./Photo Researchers

FIGURE F5.11 Cheese production
During cheese production, an enzyme preparation known as rennet is added to clot the milk. Most of the hard cheese produced in the United States today relies on rennet produced by genetically modified bacteria.

How Biotechnology Impacts Food Quality and Processing

Genetic engineering is also being used to improve the appeal and quality of food. The first genetically modified whole food available on the market was the Flavr Savr tomato, introduced in 1994. In this case, rather than adding a gene, an existing gene for an enzyme that controls ripening was inactivated to slow the ripening process and prolong the tomato's shelf life. Unfortunately, the modified tomatoes still softened, so they were difficult to harvest and ship. The Flavr Savr tomato was taken off the market because it was not economically viable. Other GM crops, such as potatoes that resist bruising and apples that don't brown, may soon be on the shelves.

Products developed through biotechnology are also used in food processing. For example, in the past the enzyme preparation rennet, which is used in cheese production, had to be extracted from calf stomachs, but now it can be produced by genetically modified bacteria (Figure F5.11). About 90% of the hard cheese made in the United States is made with genetically engineered enzymes.[13] Other enzymes, such as those used in the production of high-fructose corn syrup and the enzyme lactase, which is used to reduce the lactose content of milk, are also produced by genetically modified microorganisms. Many color and flavor additives, thickeners, and preservatives are also produced in the laboratory.

How Biotechnology Is Used in Animal Food Production

Genetic engineering is being used to improve methods of preventing, diagnosing, and treating animal disease as well as to enhance growth efficiency and fertility in food animals. The first FDA-approved application of biotechnology in animal production was the use of recombinant bovine somatotropin (bST) in dairy cows (see Chapter 17). To produce recombinant bST, scientists isolated the gene from cow cells and then inserted it into bacterial cells. The bST, which is produced in large amounts by

the bacterial cells, was then isolated and purified. The resulting product can be injected into dairy cows to increase milk production.

Biotechnology is also being applied to aquaculture. *Aquaculture*, also known as known as *fish* or *shellfish farming*, involves the breeding, rearing, and harvesting of plants and animals in ponds, rivers, lakes, and oceans. The nutritional benefits of seafood and the dwindling natural supplies have made aquaculture the fastest growing sector of animal production worldwide. Today, most of the salmon consumed in the United States is farm raised. Biotechnology allows scientists to increase the nutritional value of fish feed and identify and combine traits in fish and shellfish to increase productivity and improve quality.[14] For example, a variety of fast-growing transgenic Atlantic salmon has been developed by inserting a growth hormone gene from a related salmon species.[15] The transgenic salmon can reach market size in half the time required for a conventional Atlantic salmon.

How Biotechnology Is Used to Combat Disease

Biotechnology is used to combat human disease in several ways. Genetically engineered medications have been developed to treat disease. For example, before 1978, when bacteria were engineered to produce human insulin, people with diabetes injected insulin extracted from the pancreases of pigs and horses (see Chapter 4, *Science Applied: How the Discovery of Insulin Made Diabetes Treatable*). The genetically engineered insulin used today removes the risk of developing allergies to the animal insulins. Other engineered medications used to treat human disease include tissue plasminogen activator to dissolve blood clots, growth factors to stimulate cell replication in bone-marrow transplants, erythropoietin to treat anemia, hepatitis B vaccine, and interferon to attack viruses and stimulate the immune system.

Genetic engineering is also used to produce foods that may help combat chronic disease. Soybeans that have a higher percentage of the monounsaturated fatty acid oleic acid and vegetable oils that are higher in omega-3 fatty acids are examples of GM foods that may help lower the risk of cardiovascular disease.[16,17] Vegetable oils that have lower amounts of saturated fat are also being developed, as are soybeans that contain more of the antioxidant vitamin E than the traditional varieties.[18] Genetic engineering can also protect against cancer by increasing the amounts of certain phytochemicals in vegetables.

Biotechnology is also being used to protect health by eliminating harmful substances from food. A potato that has been genetically engineered to reduce the amounts of acrylamide (see Chapter 17) produced when the potato is fried has been approved for commercial planting.[19] And, people who are allergic to peanuts may someday enjoy peanut butter sandwiches made with peanuts that have been genetically modified to eliminate the proteins or portions of the proteins to which they are allergic.

F5.3 Safety and Regulation of Genetically Modified Foods

LEARNING OBJECTIVES

- Explain how genetic engineering might create risks for people with allergies.
- Discuss the potential impact of genetic engineering on the environment.
- Describe how genetically modified food and crops are regulated.

The rapid advance in biotechnology during the past decade has created the potential for health problems and environmental damage (Figure F5.12). Regulations are in place to control the use of genetic engineering and GM products. Despite these precautions, many consumers and scientists believe that the impact of this booming technology has not yet become apparent. They urge that this technology be used with caution to avoid health or environmental impacts that outweigh the benefits.

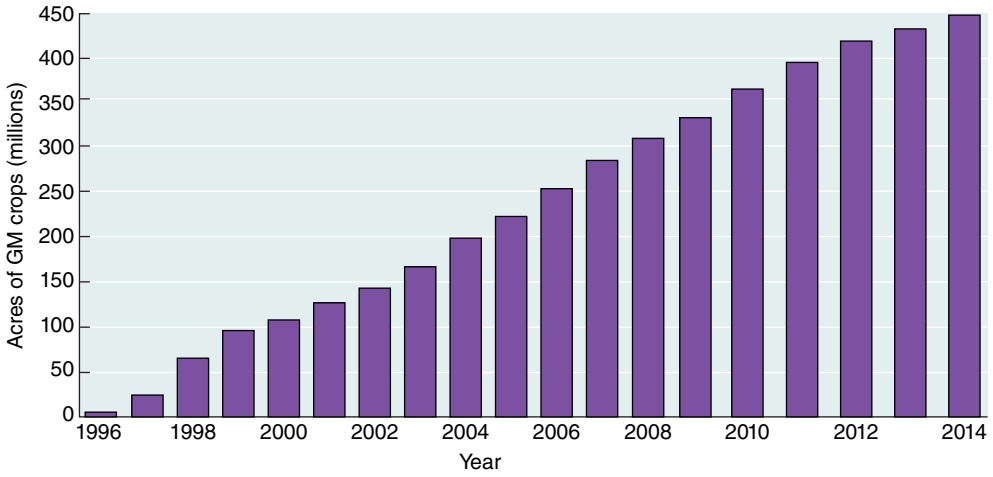


FIGURE F5.12 Worldwide growth of GM crops
Despite concerns about the impact of GM crops, the number of acres planted with them has risen steadily.[20] The most common GM crops are soybeans, corn, cotton, and rapeseed (for canola oil).

Consumer Safety

Consumer safety concerns related to bioengineered foods include the possibility that an allergen or toxin has been inadvertently introduced into a previously safe food, or that the nutrient content of a food has been negatively affected. Although foods containing ingredients derived from plant biotechnology are not generally required to carry special labels, those that contain potentially harmful allergens or toxins, or that are altered nutritionally, must be labeled. Another potential health concern is that the antibiotic resistance genes used in biotechnology may promote the development of antibiotic-resistant strains of bacteria.

Allergens and Toxins Genes code for proteins, so when a new gene is introduced into a food product, a new protein is made. These new proteins may in some cases be allergens or toxins. If a food contains a new protein that is an allergen, allergic individuals will now react to this food that may previously have been safe for them. For example, if DNA from fish or peanuts—foods that commonly cause allergic reactions—were introduced into tomatoes or corn, these foods would then be dangerous to allergic individuals. To prevent this from happening unintentionally, biotechnology companies have established systems for monitoring the allergenic potential of proteins used for plant genetic engineering.[21] Testing for the transfer of allergens has already proved to be valuable. In 1996, allergy testing successfully prevented soybeans containing a gene from a Brazil nut from entering the market.[22] If these soybeans had entered the food supply, they could have caused allergic reactions in people allergic to nuts. However, despite mandatory testing programs, individuals with food allergies cannot assume that new foods are safe.

Likewise, when a product is created using either a donor or recipient organism that is known to produce a toxin, the manufacturer must verify that the resulting product does not have high levels of the toxin. Toxins are also an issue when plants are produced by traditional breeding; toxic varieties of celery and potatoes have resulted from traditional breeding methods.

Changes in Nutrient Content Changing the proteins made by a plant or animal could also affect the nutrient content of foods. For example, tomatoes are an excellent source of vitamin C. If tomatoes were modified to have no vitamin C, people who rely on tomatoes for this vitamin might no longer get enough in their diets. As with foods containing potentially harmful allergens or toxins, foods with altered nutrient content must be labeled to disclose this information. To ensure that a GM alternative is nutritionally equivalent to the original crop, its nutritional composition is determined and its ability to maintain growth and nutritional health is assessed using experimental animals.[23]

Antibiotic Resistance There is a concern that the use of genetic engineering will spread antibiotic-resistance traits to bacteria in the environment or in the gastrointestinal tract. If pathogenic bacteria were to acquire this trait, it would make some of the antibiotics used to treat disease ineffective. The reason for this concern is that genetic engineering techniques use genes that code for

antibiotic resistance as marker genes. By inserting a marker gene along with the gene they want to transfer, scientists are able to check to see whether the gene transfer was successful. Antibiotic-resistant genes are used for this purpose because it is easy to verify that the transfer has occurred by exposing the bacteria to antibiotics—those that survive the antibiotic contain the transferred genes. Current techniques are unlikely to cause problems because the marker genes used are already widespread in the normal bacteria that inhabit the gut and in harmless environmental bacteria. In addition, markers are not used if they confer resistance to clinically important antibiotics. Newer techniques that use alternative selection systems or remove the antibiotic resistance markers before the plants leave the laboratory are becoming available.[24]

Environmental Concerns

Some of the arguments against the use of genetically modified crops are that they will reduce biodiversity, promote the evolution of pesticide-resistant insects, or create "superweeds" that will overgrow our agricultural and forest lands.

Biodiversity The ability of populations of organisms to adapt to new conditions, diseases, or other hazards depends on the presence of many different species that provide a diversity of genes. When there is biodiversity, a harmful event, such as the emergence of a new disease strain, does not eliminate all the plants—it might kill one species, but others have genes that protect them. Likewise, a drought might be harmful to some species, but others would have genes that make them drought resistant.

A concern with biotechnology is that farmers will prefer new, resistant, high-yielding crop varieties and stop planting others, causing certain varieties eventually to become extinct. For example, if every farmer began to use only genetically modified rice, then the varieties of rice that carry other traits would become extinct and those traits would be lost. If a new insect or virus emerged that killed the genetically modified rice, breeders and genetic engineers would not have the other varieties available to search for a gene that allows survival. Concerns about reduced biodiversity are not unique to genetically engineered crops. Biodiversity is also reduced when plants produced by traditional plant breeding are used to the exclusion of others.

Another school of thought suggests that genetic engineering has the potential to increase biodiversity.[25] Biotechnology can make underutilized alternative crops more suitable for widespread domestication. Genetic engineering can also introduce traits such as drought resistance and salt tolerance that would enable crops to grow in suboptimal areas. This might preserve biodiversity by reducing the need to convert areas with high biodiversity into farmland.

Superbugs and Superweeds Superbugs may arise because crops engineered to produce their own pesticides promote the evolution of pesticide-resistant insects. For example, as more farmland is planted with crops engineered to produce Bt toxin, only Bt-resistant insects can survive and reproduce. As the number of Bt-resistant insects increases, the effectiveness of Bt as a method of pest control decreases.[26,27] Although pesticide-resistant insects are an important concern, they are not just a problem caused by GM crops. Pesticide-resistant insects also arise when pesticides are sprayed on crops. To address pesticide resistance, broader insect management strategies such as integrated pest management (IPM) are being combined with the use of GM crops. Farmers who grow pesticide-resistant crops are also growing nonmodified plants in adjacent fields to provide a food supply for nonresistant insect pests. This encourages the continued existence of nonresistant pests, thereby reducing the likelihood that the number of pesticide-resistant insects will increase.

Another concern with the use of insect-resistant crops is that by reducing the population size of one insect pest, other pests may increase in numbers, becoming more significant problems.[28] For example, in China, the use of GM cotton that produces the Bt toxin has decreased the number of cotton bollworm larva. Mirid bugs, however, are not killed by Bt, so their numbers have increased, making them an important cotton pest.[29] Overuse of insect-resistant GM crops could also cause the pest population to shift to another plant population. Another concern is that the insecticides in these plants could also kill insects considered to be beneficial because they prey on insects that are crop pests.[28]

The same type of selective pressure that leads to insecticide-resistant insects can also create herbicide-resistant weeds. The proliferation of herbicide-resistant crops has promoted the evolution of weeds that are resistant to these herbicides.[17] As with superbugs, herbicide-resistant

Chris Knapton/Photo Researchers

FIGURE F5.13 Field testing GM crops
Field tests of genetically modified crops attempt to determine the impact of the new crops on the environment and how well the plants function. The Animal and Plant Health Inspection Service of the USDA regulates field tests.

weeds are not unique to GM crops; they had arisen even before GM crops were developed due to application of herbicides to crops.[23] Adjustments in the amounts and types of herbicides and the use of other methods of weed control, such as IPM techniques, are being used to solve the problem.[23]

It has also been suggested that fast-growing superweeds could result if a plant that has been modified to grow faster or to better survive begins growing in areas beyond the farmer's field, or if the genes inserted to produce hardy, high-yield, fast-growing crops could be transferred to wild relatives by natural cross-breeding. Most experts do not feel that the "escape" of a GM domestic crop is a major concern because domesticated crops depend on a managed agricultural environment and carry traits that make them unable to compete in the wild. Although the transfer of genes that might give weeds an advantage is a possibility, it is unlikely. For cross-breeding to occur between a genetically modified plant and a weed growing nearby, both plants would have to be closely related species and would have to flower at the same time. Even if cross-breeding did occur, the chance that the new plant would have inherited traits that enhance its survival is very small. As a further safeguard to prevent environmental risks, most developers avoid adding traits that could increase the competitiveness or other undesirable properties in weedy relatives.

Regulation of Genetically Engineered Food Products

Although the U.S. government does not scrutinize every step in the development of new plant varieties, it is involved in overseeing the process. The government sets guidelines to help researchers address safety and environmental issues at all stages, from the early development of genetically engineered plants through field testing and ultimately commercialization. Companies that develop new plant varieties must provide data to support the safety and wholesomeness of the product. Crops created by both traditional breeding and biotechnology methods must be field tested for several seasons to make sure only desirable changes have been made (Figure F5.13). Plants are examined to ensure that they look right, grow right, and produce food that is safe and tastes right. Analytical tests must be performed to determine if the levels of nutrients in the new variety are different and if the food is safe to eat. The FDA, the USDA, and the EPA are all involved in the oversight of plant biotechnology.[30]

The Food and Drug Administration (FDA) The FDA has jurisdiction over the safety of foods in the marketplace and therefore regulates the safety and labeling of all foods and animal feeds derived from crops, including genetically modified crops.

What Determines the Safety of GM Foods? The FDA works from the principle that safety should be determined on the basis of the characteristics of a food or food product, not the method used to produce it. Foods developed using biotechnology are therefore evaluated to determine their equivalence to foods produced by traditional plant breeding. Emphasis is placed on whether the food creates a new or increased allergenic risk, has an increased level of a naturally occurring toxin, contains a substance not previously present in the food supply, or is nutritionally different from the traditional plant. Although premarket approval is required only when the new food contains substances not commonly found in foods or contains a substance that does not have a history of safe use in foods, the FDA recommends that developers consult with the FDA regarding genetically engineered foods under development and submit a scientific and regulatory assessment 120 days before the food is marketed.[30]

Labeling GM Foods As with food safety, the FDA's food labeling policies focus on the characteristics of a food, not on how it is produced. For example, virtually all plants have been genetically modified through traditional plant breeding, but the FDA does not require declarations about those modifications. Under this precedent, labeling decisions are based on whether there are differences between the GM food and the traditional food. Foods containing GM ingredients must be labeled as such only if the nutritional composition of the food has been altered; if it contains potentially harmful allergens, toxins, pesticides, or herbicides; if it contains ingredients that are new to the food supply; or if the food has been changed significantly enough that its traditional name no longer applies.

Some people believe that all foods that contain GM ingredients should be labeled as such so that consumers who want to avoid these foods could do so. For instance, a vegan may want

to know if the zucchini he or she is about to consume contains some DNA from an animal. However, the FDA stance is that plants and animals already share many of the same DNA segments and such labeling would be misleading, since foods that are not different in quality, nutrient composition, and safety would be viewed as somehow different from traditional foods (Figure F5.14).

Cost is also a consideration. If labeling regulations change, manufacturers would need to add labels to the hundreds, if not thousands, of food products containing GM ingredients. DNA-modified plants would need to be segregated during planting and harvesting, and products containing ingredients from them would require different manufacturing, transport, and storage facilities. Despite these costs, however, the need to sell to markets such as the European Union that do not want GM crops is already compelling U.S. farmers to separate and label GM crops.

© Vanessa Miles/Alamy Limited

FIGURE F5.14 Labeling GM foods
Whether the label is voluntary or mandatory, designing an appropriate label is a complex issue. Some companies are voluntarily labeling foods as "Grown from genetically modified seed." The FDA feels that these simple labels will imply to some people that the product is inherently better than other products, while other people will feel this means that the food is more dangerous than others. However, a more detailed label that describes how a particular product was modified would be too lengthy and would not be understood by many consumers.

THINK CRITICALLY

Do you think GM ingredients are different enough from ingredients produced without genetic engineering to warrant the economic and logistical costs involved in providing this information on food labels?

U.S. Department of Agriculture (USDA) The USDA regulates agricultural products and research on the development of new plant varieties. The Animal and Plant Health Inspection Service (APHIS) of the USDA helps to ensure that the cultivation of a new plant variety poses no risk to agricultural production or to the environment. For example, if there is a high probability that a new plant variety will cross-breed with a weed and that the transfer of the new trait could allow the weed plant to survive better, APHIS will not allow further development of this plant. If a plant has been studied and tested and does not pose environmental risks, field testing is allowed. APHIS continues to oversee the testing until it is determined that the plant is safe.

Environmental Protection Agency (EPA) The EPA regulates any pesticides that may be present in foods and sets tolerance levels for these pesticides. This includes genetically modified plants that can protect themselves from insects or disease. The EPA assesses the safety of the protein that confers the insect or disease resistance for human consumption, for other organisms, and for the environment.

CHAPTER OUTLINE

18.1 The Two Faces of Malnutrition
The Impact of Undernutrition
Overnutrition: A World Health Problem
Why Undernutrition and Overnutrition Exist Side by Side

18.2 Causes of Hunger and Undernutrition
Food Shortages
Poor-Quality Diets

18.3 Eliminating World Hunger
Providing Short-Term Food Aid
Eliminating Poverty
Providing Enough Food
Ensuring a Nutritious Food Supply
Providing Education

18.4 Hunger at Home
Causes of Food Insecurity
Federal Programs to Prevent Malnutrition

(©iStockphoto)

AFP/Getty Images, Inc.

World Hunger and Malnutrition

18

CASE STUDY

Teresa, a Peace Corps volunteer, recently arrived in Rwanda to help care for children in a rural health clinic. She is struck by the number of children suffering from diarrhea and intestinal parasites. Most of the children appear small for their age and are underweight. She often sees children she thinks are 5 or 6 years old, only to discover that they are 10 or 11. She is told that the growth retardation is the result of chronic undernutrition. A small 2-year-old boy named Songe catches her eye. His hair is an odd color, his legs are scrawny, and his belly is bloated, but he is not as emaciated as some of the other malnourished children she sees. His mother says that his symptoms began shortly after his younger brother was born. After a bout of diarrhea, he became lethargic and eventually stopped growing.

© MissHibiscus/iStockphoto

The clinic nurse explains to Teresa that Songe is suffering from protein-energy malnutrition. When his brother was born, Songe stopped nursing at his mother's breast and started eating the adult diet, which is high in starch and fiber. He was not getting enough protein to support the needs of his growing body. His belly is bloated because his abdomen is filling with fluid and his liver is filling with fat. There is not enough protein in his blood to hold the fluid there, so it seeps into his abdomen; nor is there enough protein to transport fat, so it accumulates in his liver. Songe's health is also being affected in ways that are less visible. Without adequate protein, his immune system cannot function normally, increasing his susceptibility to infections and making the immunizations provided in the clinic less effective.

To treat his malnutrition, the clinic provides Songe with a special high-protein drink to consume along with his regular diet. **Teresa is concerned that when Songe stops consuming the protein supplement, his malnutrition will return.**

18.1 The Two Faces of Malnutrition

LEARNING OBJECTIVES

- Compare the problems of under- and overnutrition in the world today.
- Discuss the impact of malnutrition throughout the life cycle.
- Describe the relationship between malnutrition and infectious disease.
- Explain how nutrition transition affects the incidence of obesity.

hunger Recurrent involuntary lack of food that over time may lead to malnutrition.

starvation A severe reduction in nutrient and energy intake that impairs health and eventually causes death. It is the most extreme form of malnutrition.

For most of us, the image that comes to mind when we think of malnutrition around the world is one of **hunger** and **starvation**. The nations at risk change, but the soulful eyes and bloated bellies of the starving children remain. About 805 million people around the world are chronically undernourished; almost half of all deaths in children under 5 years of age are linked to undernutrition, which kills over 6 million children each year.[1,2] At the same time that global health organizations are struggling with issues of undernutrition, the incidence of illnesses related to overconsumption is soaring. The overweight and the undernourished both suffer from malnutrition and experience high levels of sickness and disability, shorter life expectancies, and lower levels of productivity. These two faces of malnutrition exist together, complicating the goal of solving the problem of malnutrition worldwide.

The Impact of Undernutrition

LIFE CYCLE

cycle of undernutrition A cycle in which undernutrition is perpetuated by an inability to meet nutrient needs at all life stages.

In populations where undernutrition is a chronic problem, there is a **cycle of undernutrition** (Figure 18.1). The cycle begins when women consume a deficient diet during pregnancy. These

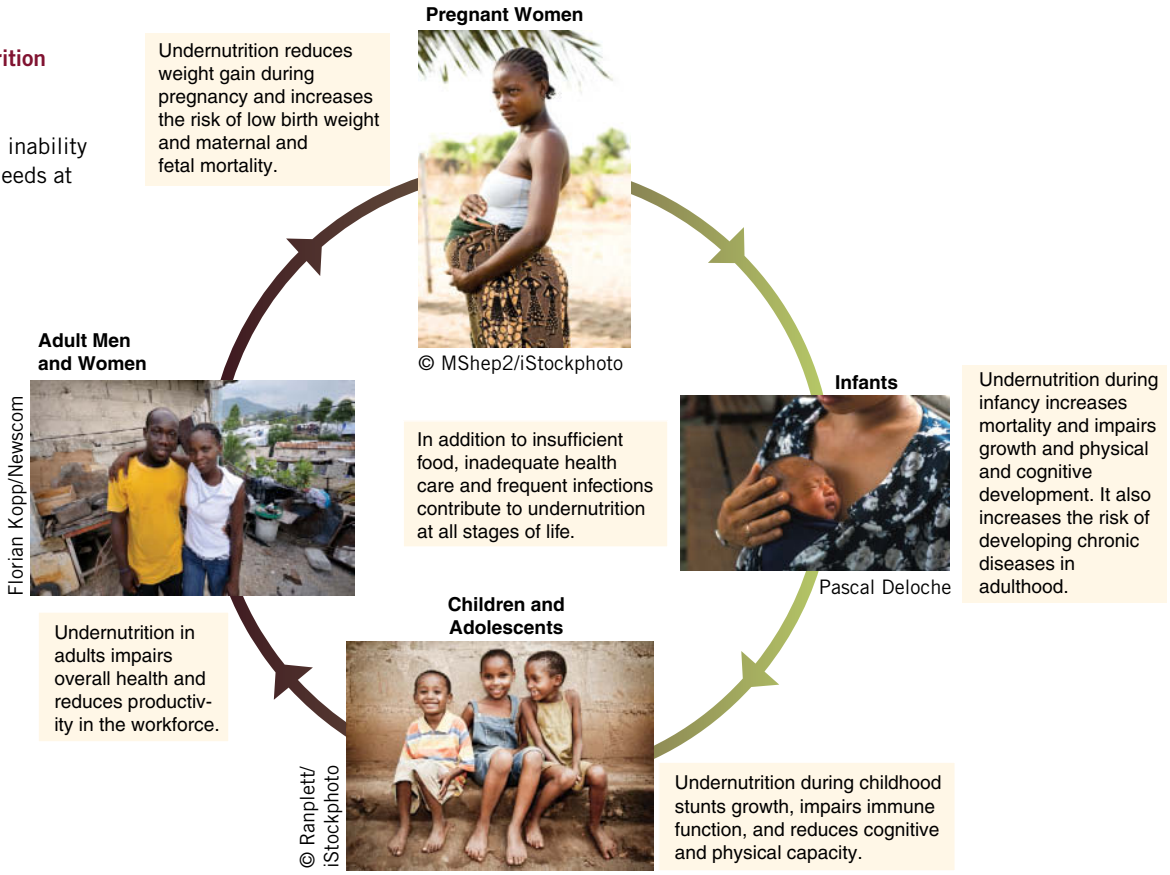


FIGURE 18.1 Undernutrition through the lifecycle
Undernutrition impairs the health of individuals at every stage of life. It often begins in the womb, continues through infancy and childhood, and extends into adolescent and adult life, where it reduces productivity and the ability to live a healthy life.

women are more likely to give birth to low-birth-weight infants who are susceptible to illness and early death. The children who do survive may be small, weakened physically, and intellectually impaired. They grow into undernourished adults, who are also susceptible to disease and unable to contribute optimally to economic and social development. The women in this next generation also begin their pregnancies poorly nourished and are therefore likely to give birth to low-birth-weight infants. Interruption of this cycle of undernutrition at any point can benefit the individuals and the society. Healthy children can then grow into healthy adults who produce healthy offspring and can contribute fully to society.

infant mortality rate The number of deaths during the first year of life per 1000 live births.

stunting A decrease in linear growth rate that is an indicator of nutritional well-being in populations of children.

Low Birth Weight Contributes to High Infant Mortality Low-birth-weight infants—those weighing less than 5.5 lb (2.5 kg) at birth—are at greater risk of complications, illness, and early death than normal-weight infants. More low-birth-weight infants means a higher **infant mortality rate**, the number of deaths per 1000 live births in a population. The infant mortality rate and the number of low-birth-weight births are indicators of the health and nutritional status of a population. In industrialized countries like Sweden, the United States, and Japan, the infant mortality rate is less than 7 per 1000 live births; in developing countries including Chad, Somalia, and Afghanistan, the rate is over 90 per 1000 live births (Table 18.1).[3] Low-birth-weight infants who do survive require extra nutrients, which are usually not available. Malnutrition in infancy and childhood has a profound effect on cognitive development and physical growth and development as well as on susceptibility to infectious disease.

Ton Koene/Zuma Press/Newscom

FIGURE 18.2 Stunting is an indicator of undernutrition Stunted children may never regain the height lost as a result of undernutrition. Stunting also impairs the development of vital organs, reducing life expectancy.

Undernutrition Stunts Growth Undernourished children grow poorly. The prevalence of decreased growth in height, referred to as **stunting**, is used as an indicator of the well-being of a population's children (Figure 18.2). It is estimated that about 25% of children under 5 years of age are stunted; about half of these children live in Asia and one-third in Africa.[4] Deficiencies of energy, protein, iron, and zinc, as well as prolonged infections, have been implicated as causes. Stunting in childhood produces smaller adults who have a reduced work capacity. Stunted women are more likely to give birth to low-birth-weight babies. In addition, those who had lower birth weights and early childhood stunting are more likely to have abdominal obesity in adulthood.[5] Abdominal obesity increases the risk of morbidity from cardiovascular disease, hypertension, and diabetes.

Undernutrition Increases the Risk of Infections Undernourished children have depressed immune systems, which reduces their ability to resist infection. Therefore, infectious

TABLE 18.1 Indicators of Poverty and Malnutrition[3]

	Infant mortality (deaths/1000 live births)	Life expectancy (years)	Literacy (percentage of population)	Access to medical care (physicians/1000 people)
More developed countries				
United States	6.2	79.6	99	2.45
Australia	4.2	82.1	99	3.27
Japan	2.1	84.5	99	2.3
Israel	4.0	81.3	97.8	3.35
Germany	3.5	80.4	99	3.69
Less developed countries				
Afghanistan	117.2	50.5	31.7	0.23
Angola	80.0	55.3	70.6	0.17
Ghana	38.5	65.8	71.5	0.1
India	43.2	67.8	74	0.7
Cambodia	51.4	63.8	73.9	0.23

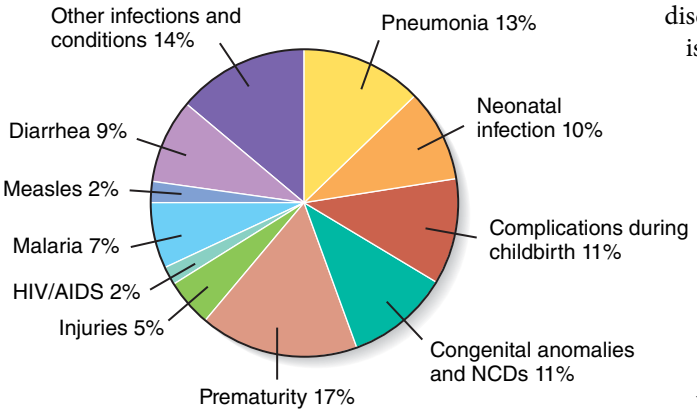


FIGURE 18.3 Causes of death among children under 5 years of age[6]
Infections are the leading cause of death in children from birth to 5 years of age. Mortality from infectious diseases, such as measles, diarrheal diseases, and respiratory infections, is increased in malnourished children.

diseases are more common and more severe in undernourished children. Mortality from infections is increased among malnourished children; they may die of infectious diseases that would not be life threatening in well-nourished children. About half of all deaths in children under 5 years of age are due to infectious disease (Figure 18.3).[6] The presence of undernutrition is an underlying cause in an estimated 45% of deaths in children under age 5.[2] Even immunization programs, designed to reduce the incidence of infectious disease, may be ineffective because the immune systems of undernourished individuals cannot respond normally. Infection also contributes to and worsens malnutrition. The infective process increases nutrient needs as well as nutrient losses, thereby making it difficult even for adequately nourished children with infections to meet their needs.

Overnutrition: A World Health Problem

For the first time in human history, the number of overweight people rivals the number who are underweight.[7] Around the world, more than 1.9 billion adults are overweight or obese; over 600 million are obese. The prevalence of obesity doubled between 1980 and 2014.[8] Once considered a problem only in high-income countries, overweight and obesity are now on the rise in low- and middle-income countries, particularly in urban settings. If recent trends continue, by 2030, up to 57.8% of the world's adult population could be either overweight or obese.[9] This increase has created what has been called a *double burden of disease*; as developing countries continue to struggle with problems of undernutrition, they are faced with rising rates of cardiovascular disease, hypertension, type 2 diabetes, and other noncommunicable diseases (NCDs) associated with obesity (Figure 18.4). It is not uncommon to find undernutrition and obesity existing side by side within the same country, the same community, and even within the same household.[10]

nutrition transition A series of changes in diet, physical activity, health, and nutrition that occurs as poor countries become more prosperous.

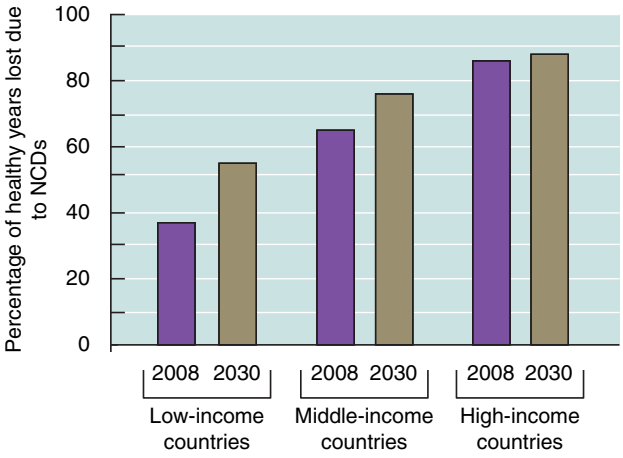


FIGURE 18.4 Rising rates of noncommunicable diseases
This graph shows the percentage of the total years of productive life that are lost due to NCDs in low-, middle-, and high-income countries in 2008 and the percentage projected by 2030.

The growing prevalence of obesity among children is also a major concern. Latest estimates suggest that 42 million children under 5 years of age are overweight.[8] In some countries a high prevalence of overweight children now exists alongside a high frequency of undernourished children. Overweight and obese children are likely to stay that way into adulthood and are more likely to develop diseases such as diabetes and cardiovascular disease at a younger age.

Why Undernutrition and Overnutrition Exist Side by Side

We see the problems of undernutrition and overnutrition existing side by side because diets and lifestyles change as economic conditions improve. Traditional diets in developing countries are based on a limited number of foods—primarily starchy grains and root vegetables. As incomes increase and food availability improves, the diet becomes more varied, and energy intake increases with the addition of meat, milk, and other more energy-dense foods. Along with this **nutrition transition**, there is a decrease in activity due to less physically demanding occupations, greater access to transportation, more labor-saving technology, and more passive leisure time (Figure 18.5).

Some of the effects of this nutrition transition are positive: Life expectancy increases, and the frequencies of low birth weight, stunting, infectious diseases, and nutrient deficiencies decrease. However, at the same time, rates of heart disease, cancer, diabetes, obesity, and childhood obesity increase.[8] Transition to a diet high in animal protein and refined foods also increases the use of natural resources and in the long term may deplete nonrenewable resources.

THINK CRITICALLY

In 2008, 80% of NCD deaths were in developing countries. Based on the percentages shown in the graph, how is that possible?

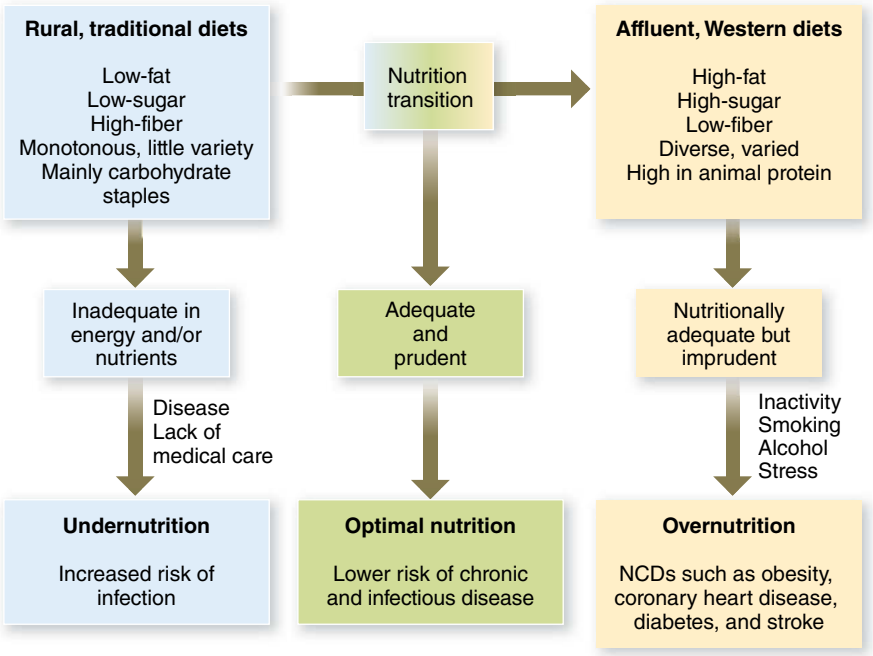


FIGURE 18.5 Nutrition transition changes the pattern of disease
This schematic shows the dietary changes and nutritional consequences of nutrition transition. The traditional rural diet is often inadequate in energy, protein, or micronutrients. The affluent Western diet meets nutrient needs but contributes to nutrition-related NCDs such as obesity and heart disease. A diet that falls somewhere between these extremes is optimal for health.

18.2 Causes of Hunger and Undernutrition

LEARNING OBJECTIVES

- Discuss the factors that cause food shortages for populations and for individuals.
- Explain the concept of food insecurity.
- List three common nutrient deficiencies worldwide and explain the consequences of these deficiencies.

famine A widespread lack of access to food due to a disaster that causes a collapse in the food production and marketing systems.

The specific reasons for hunger vary with the time and place, but the underlying cause is that the food available in the world is not distributed equitably. This inequitable distribution results in either not enough food or the wrong combination of foods to meet nutrient needs. This in turn results in protein-energy malnutrition and micronutrient deficiencies.

Food Shortages

The most obvious example of a food shortage is **famine**. Famine is a widespread failure in the food supply due to a collapse in the food production and marketing systems. Drought, floods, earthquakes, and crop destruction by diseases or pests are natural causes of famines (Figure 18.6). Man-made causes include wars and civil conflicts. Regions that produce barely enough food for survival under normal conditions are vulnerable to the disaster of famine. This situation is analogous to a man standing in water up to his nostrils: if all is calm, he can breathe, but if there is a ripple, he will drown. When a ripple such as a natural or civil disaster occurs, it cuts the margin of survival and creates famine.

Alison Wright/NG Image Collection

FIGURE 18.6 Causes of famine
After the earthquakes in Haiti, survivors lived in makeshift camps such as this one. This natural disaster destroyed the infrastructure that once distributed food throughout the country, resulting in famine.

Food shortages due to famine are very visible because they cause many deaths in one area during a short period of time, but chronic food shortages take a greater toll when it comes to the number of hungry people in the world. Chronic shortages occur when economic inequities result in lack of money, health care, and education for populations or individuals within populations; when the food supply is insufficient to feed the population; when cultural and religious practices limit food choices; or when environmental resources are misused, limiting the ability to continue to produce food.

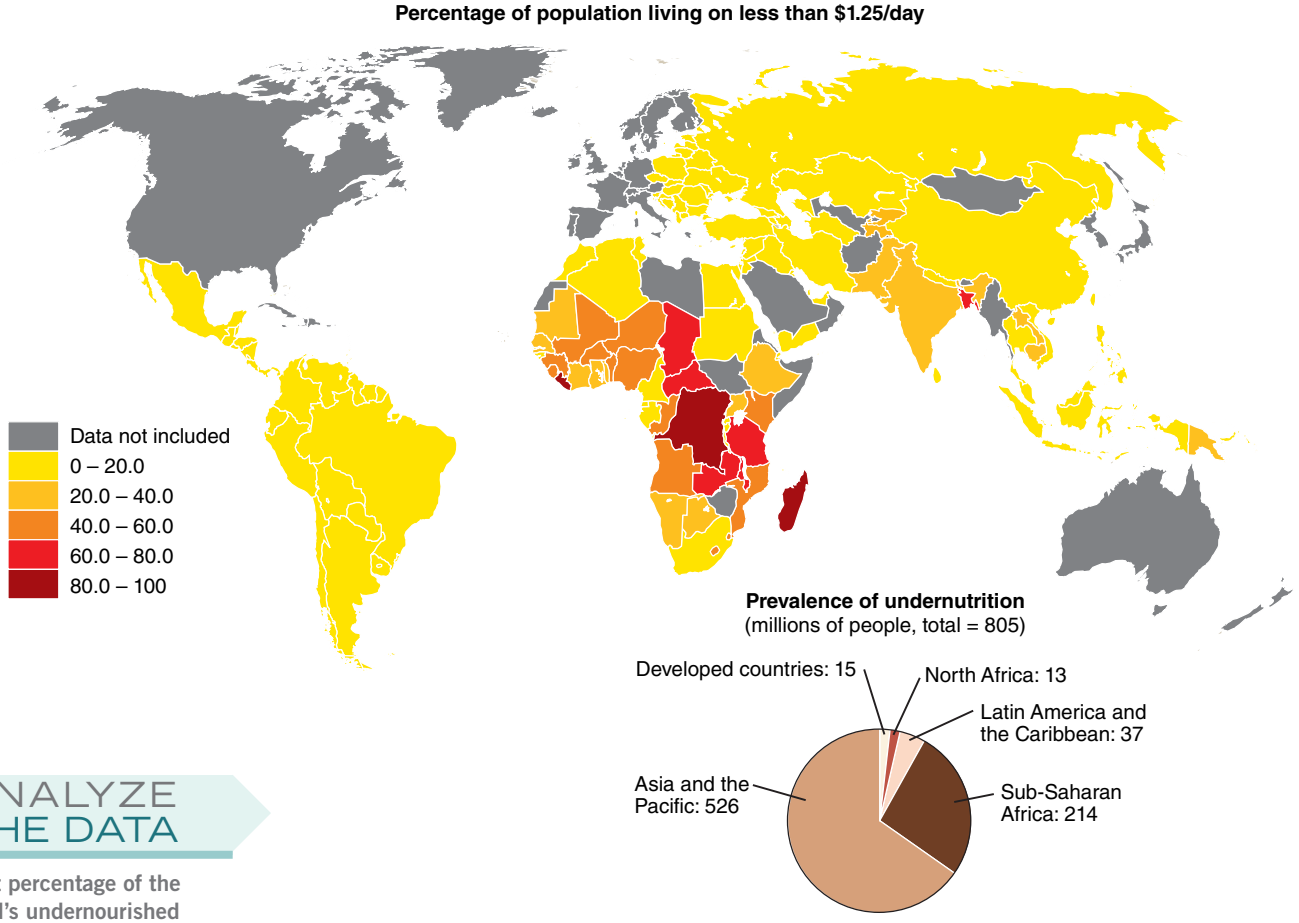
Poverty Almost 1.2 billion people in the developing world currently live below the international poverty line, earning less than $1.25/day.[11] Poverty is central to the problem of hunger and undernutrition; in most parts of the world their incidence is almost identical (Figure 18.7). Poverty creates **food insecurity**, or the limited ability to acquire nutritious, safe foods. Food insecurity can occur in countries, in households, and among individuals. In wealthy countries, social safety nets, such as soup kitchens, government food assistance programs, and job training programs, help the hungry to obtain food or money to buy food. In poor countries, a family that cannot grow enough food or earn enough money to buy food may have nowhere to turn for help.[12]

food insecurity A situation in which people lack adequate physical, social, or economic access to sufficient, safe, nutritious food that meets their dietary needs and food preferences to lead an active and healthy life.

VIDEO

Disease and disability are more prevalent among the poor. Poverty reduces access to health care, so disease goes untreated (see Table 18.1). When left untreated, illness increases nutrient needs and further limits the ability to obtain an adequate diet, contributing to malnutrition. Lack of immunizations and medical treatment increases the incidence of and morbidity from infectious disease and decreases survival rates from NCDs such as cancer. Lack of health care also increases infant mortality and the incidence of low-birth-weight births.

The poor have less access to education, which reduces the opportunities to escape poverty. It also increases the risk of undernutrition and disease because lack of education leads to inadequate care for infants, children, and pregnant women. A lack of education about food preparation and storage can



ANALYZE THE DATA

What percentage of the world's undernourished people live in developing countries?

FIGURE 18.7 Poverty increases malnutrition
The regions of the world where poverty is the most prevalent (see map)[13] correspond to the regions where the greatest numbers of undernourished people live (see pie chart).[1]

affect food safety and the health of the household—unsanitary food preparation increases the incidence of gastrointestinal diseases, which contribute to malnutrition.

Overpopulation Overpopulation exists when a region has more people than its natural resources can support. A fertile river valley can support more people per acre than can a desert environment. But even in fertile regions of the world, if the number of people increases too much, resources are overwhelmed and food shortages occur.

The human population is currently growing at a rate of more than 80 million people per year, and most of this growth is occurring in developing countries (Figure 18.8).[14] These countries cannot escape from poverty because their economy cannot keep pace with the rate of population growth. Efforts to produce enough food can damage the soil and deplete environmental resources, further reducing the capacity to produce food in the future. The problem of hunger today is due primarily to the unequal distribution of resources, but as the world's population continues to increase, both producing enough food and distributing it equitably are likely to be problems.[15]

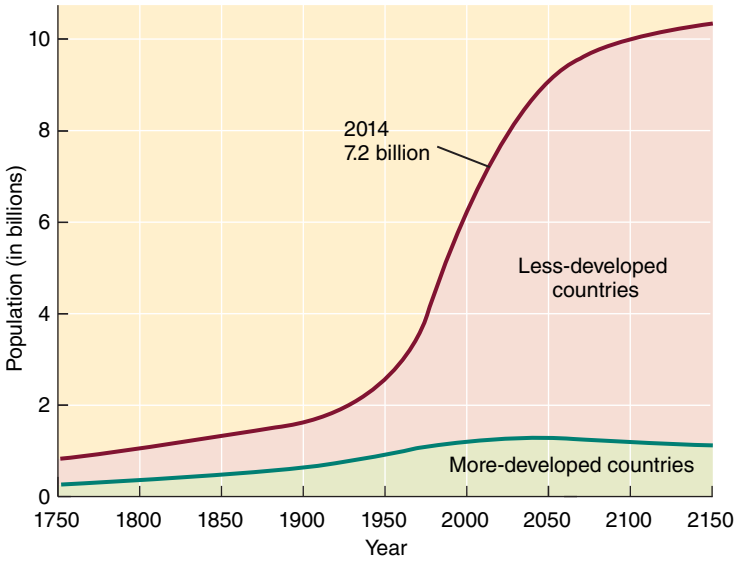


FIGURE 18.8 World population growth
Since about 1950, most of the increase in world population has occurred in developing countries, and this trend is expected to continue.

Cultural Practices In some cultures, access to food may be limited for certain individuals within households. For example, women and girls may receive less food than men and boys, because culturally they are viewed as less important. How much food is available to an individual within a household depends on gender, control of income, education, age, birth order, and genetic endowments.

The cultural acceptability of foods also contributes to food shortages and malnutrition. If available foods are culturally unacceptable, a food shortage exists unless the population can be educated to use and accept new foods. For example, insects are eaten in some cultures and provide an excellent source of protein, but they are unacceptable to people in other cultures.

Limited Environmental Resources The land and resources available to produce food are limited. Some resources, such as minerals and fossil fuels, are present in the Earth in finite amounts and are nonrenewable—that is, once used they cannot be replaced in a reasonable amount of time. Other resources such as soil and water are **renewable resources** because they will be available indefinitely if they are used at a rate at which the Earth can restore them. For example, when agricultural land is used wisely—crops rotated, erosion prevented, contamination limited—it can be reused almost endlessly. However, if land is not used carefully, damage caused by soil erosion, nutrient depletion, and accumulation of pollutants may reduce the amount of usable land over the long term.

renewable resources
Resources that are restored and replaced by natural processes and that can therefore be used forever.

How Modern Agriculture Affects Natural Resources Modern mechanized agricultural methods increase yields, but use more energy and resources and cause more environmental damage than traditional labor-intensive farming. In the United States, it is estimated that 15.7% of energy consumed is used to produce food.[16]

As more countries undergo nutrition transition, the demand for meat-based diets is increasing.[17] Raising cattle uses rangeland, grain, water, and fossil fuels, and creates both air and water pollution. The animals themselves produce methane gas in their gastrointestinal tracts, which enters the air and contributes to the greenhouse effect. Large-scale "factory farming" makes the problem worse because additional methane is produced when animal sewage is stored in ponds and heaps. Livestock is responsible for about 18% of greenhouse gas emissions, more than all the cars in the world combined.[18]

In general, the environmental cost of producing plant-based foods is lower than that of producing animal products, but the cost may still be substantial. Modern large-scale farming can erode the soil and deplete its nutrients. Fertilizers used to restore soil and pesticides used to kill insects can contaminate groundwater and eventually waterways. And if the plant products are shipped long distances, require refrigeration, or need other types of processing, the environmental costs are increased even more (see **Debate: Are Vegetarian Diets Better for People and for the Environment?**).

DEBATE

Are Vegetarian Diets Better for People and for the Environment?

It takes 18 times more land, 10 times more water, 9 times more fuel, 12 times more fertilizer, and 10 times more pesticide to produce 1 kg of protein from beef than from kidney beans.[23] So it makes sense that eliminating animals from our diet would reduce the environmental impact of human food production. But what if the vegetarian diet relies on foods like frozen pizza and breaded, extruded soy nuggets that are individually wrapped in plastic and shipped across the country? Is the elimination of animal foods the answer to saving the planet and feeding the world?

USDA/Photo Researchers

Grazing cattle on land that is unfit for growing crops preserves arable land for human food production.

Those who promote a vegetarian world argue that producing animal products consumes large amounts of energy, destroys forests and grazing lands, and pollutes the air and water. These problems, in turn, limit the amount of food that can be produced and thus contribute to world hunger. Vegetarian advocates also point out the reduction in chronic disease risk that is associated with a vegetarian diet. Although these arguments are valid in some instances, the impact food animals have on the environment and on nutrient intake depends on how they are integrated into the ecosystem and the overall dietary pattern.

On a small farm, animals are typically part of the ecosystem. They are fed crop wastes, kitchen scraps, and grasses that people cannot eat and produce meat, eggs, and milk that can nourish people. Animal manure is used for fertilizer in local fields. However, much of the meat that humans eat is produced in large agribusinesses where animals are fed grain grown on land that could be used to grow human food; crops grown to feed animals use 33% of total arable land worldwide.[18] Humans who eat these animals then get back only a fraction of the food energy they could have gotten from eating the grain that was fed to the animals. Animal waste on these huge farms builds up rapidly. It causes runoff that can pollute nearby waterways, and releases gases into the atmosphere that contribute to acid rain and climate change.

The food choices vegetarians make also affect the environmental impact of a vegetarian diet. A vegetarian diet can be made up of soy nuggets and French fries or it can be based on locally grown, minimally processed grains, legumes, nuts, and fruits and vegetables. The soy-nugget meal is likely to be lacking in essential nutrients and could actually take more resources to produce than a meat-based meal. It has been suggested that switching from a beef- and milk-based diet to a diet relying on highly refined protein substitutes, such as texturized soy protein, could actually increase the amount of arable land needed to produce food for humans.[24] Packaging, processing, and transportation have a significant environmental impact and need to be factored into the overall impact of vegetarian diets.

Even if everyone made environmentally sound vegetarian choices, eliminating animal products still may not be the best nutritional choice. In the developing world, small amounts of meat and milk in the diet can mean the difference between survival and starvation. In the United States, animal foods provide important sources of vitamin B_{12}, calcium, and highly absorbable forms of iron and zinc. Eliminating animal products would reduce both the variety and nutrient content of the human diet.

So should everyone eat a vegetarian diet? Is it best for nutritional health and the health of the planet? Whatever your view, finding a diet that supports health and the environment is not simple.

THINK CRITICALLY: If you stopped eating meat tomorrow, what would be the main source of protein in your diet?

In addition to an increase in the demand for grain to feed livestock, there has been a sharp acceleration in the use of grain to produce ethanol to fuel cars.[19] The increased demand has contributed to dramatic increases in food prices, which have made it even more challenging for low- and middle-income families worldwide to obtain enough food. The rising price of grain and fuel oil has also reduced the amount of food aid, widening the gap between the amount of food available and the amount needed to meet nutritional needs.[20]

Depletion of Ocean Resources It is not only the resources of the land that are at risk. Throughout human history, fish from the world's oceans have been an important source of protein. However, increases in population have increased demand for seafood to the point that the Earth's oceans are being depleted.[21] Because the ocean is open to fishermen from around the world, its use has been difficult to control. Many marine species have been harvested until their numbers are severely reduced. Pollution also threatens the world's fishing grounds. Oil spills and deliberate dumping can occur offshore, and sewage, pesticides, organic pollutants, and sediments from erosion wash into coastal waters where most fish and shellfish spend at least part of their lives. Even aquaculture, which has the potential to meet the world's demand for seafood, creates pollution, depletes resources, and damages the environment if not managed wisely (Figure 18.9).[22]

The Star/picture alliance/ANN/Newscom

FIGURE 18.9 Environmental impact of aquaculture Aquaculture has great potential to alleviate hunger, but the waste produced by thousands of fish concentrated in open net pens such as those shown here can damage the local environment if not managed carefully.

Poor-Quality Diets

Even when there is enough food, undernutrition can occur if the quality of the diet is poor. The typical diet in developing countries is based on high-fiber grain products and has little variety. Adults who are able to consume a relatively large amount of this diet may be able to meet their nutrient needs. But those with increased needs or a limited capacity to consume these foods are at risk for nutrient deficiencies. Children, pregnant women, and the elderly, especially if they are ill, may not be able to eat enough of this bulky grain diet to meet their needs. Deficiencies of protein, iron, iodine, and vitamin A are common because of poor-quality diets (Table 18.2).

Protein-Energy Malnutrition Protein and energy deficiencies usually occur together and are most common in children. The most severe form, severe acute malnutrition (SAM), affects more than 20 million children worldwide; the fatality rate among children hospitalized with SAM can be as high as 50%.[25] When there is a general lack of food, marasmus results, but when the diet is limited to starchy grains and vegetables, protein deficiency can predominate, particularly in individuals with high protein needs—those who are growing, developing, suffering from infection, or healing. Kwashiorkor, a deficiency of protein but not energy, occurs when protein needs are high and the available diet is low in protein (see Chapter 6). It is common in children over 18 months of age when the main food is a bulky cereal grain low in high-quality protein. Children have high protein needs and small stomachs, so, although they may be able to eat enough grain to meet their energy needs, they are not able to consume enough to meet their protein needs (Figure 18.10).

Iron Deficiency Iron deficiency is the most common nutritional deficiency worldwide; 2 billion people have iron deficiency anemia, the most severe stage of iron deficiency.[26] The causes of iron deficiency include a limited dietary iron intake and increased losses due to infection. The diet in most developing countries is based on plant foods, which only

TABLE 18.2 The Consequences of Malnutrition Throughout Life

Life stage	Common deficiencies	Consequence
In utero	Energy	Low birth weight
	Iodine	Brain damage
	Folate	Neural tube defects
Infant/young child	Protein, energy	Growth retardation, increased risk of infection
	Iron	Anemia
	Iodine	Impaired cognitive development, goiter
	Vitamin A	Infection, blindness
Adolescent	Protein, energy	Stunting, delayed growth
	Iron	Anemia
	Iodine	Impaired cognitive development, goiter
	Vitamin A	Infection, blindness
	Calcium	Inadequate bone mineralization
Pregnant woman	Protein, energy	Intrauterine growth retardation, increased mortality of mother and fetus
	Folate	Maternal anemia, neural tube defects in infants
	Iron	Maternal anemia
	Iodine	Cretinism in infant, goiter in mother
	Vitamin A	Infection, blindness
Adult	Energy, protein	Underweight, lethargy
	Iron	Anemia
Elderly adult	Energy	Underweight, lethargy
	Calcium, vitamin D, and protein	Osteoporosis fractures, falls

© Bruce Brander/Photo Researchers, Inc.

Marasmus

© Alison Wright/NG Images

Kwashiorkor

FIGURE 18.10 Marasmus and kwashiorkor
A general lack of food causes the wasting associated with marasmus; too little protein to meet needs causes kwashiorkor, which is characterized by a bloated belly.

THINK CRITICALLY

Why are children more likely to develop kwashiorkor than adults?

provide poorly absorbed nonheme iron. The risk and severity of dietary iron deficiency is further increased in developing countries by the high prevalence of intestinal parasites, which cause gastrointestinal blood loss, and acute and chronic infections, such as malaria (Figure 18.11).

Iron deficiency can have a major impact on the health and productivity of a population. Anemia during pregnancy increases the risk of maternal and fetal mortality, premature delivery, and low birth weight. Iron deficiency in infants and children can stunt growth, retard mental development, decrease resistance to infection, and increase morbidity due to disease. In older children and adults, it causes fatigue and decreases productivity.

Iodine Deficiency Iodine is an essential trace element that is a constituent of the thyroid hormones (see Chapter 12). Globally, nearly 2 billion people, including 285 million school-age children, have inadequate iodine intake.[37] A deficiency of iodine in the food supply affects virtually all segments of the community. During pregnancy, iodine deficiency increases the incidence of stillbirths, spontaneous abortions, and developmental abnormalities such as cretinism in the offspring.[38] Although goiter is the most visible symptom of iodine deficiency (Figure 18.12), cretinism is the most severe manifestation. Cretinism is characterized by impaired cognitive development, deaf mutism, and growth failure. It is devastating to individuals and families, but the more subtle effects of iodine

deficiency on intellectual performance and work capacity may have a greater impact on the population as a whole. Iodine-deficient children have lower IQs and impaired school performance. Iodine deficiency in children and adults is associated with apathy and decreased initiative and decision-making capabilities. Worldwide, iodine deficiency diseases are believed to be one of the main causes of impaired cognitive development in children.

Iodine deficiency occurs in regions with iodine-deficient soil that rely extensively on locally produced food. The eastern Mediterranean region and Africa have the highest incidence of iodine deficiency disorders. Because soil iodine is low in regions where deficiency is common, the problem can be solved only by importing foods high in iodine or by adding iodine to the local diet through fortification or supplementation. As discussed later in this chapter, the introduction of iodized salt is the most common way that iodine intake is increased in populations at risk of deficiency (see Chapter 12).

Vitamin A Deficiency It is estimated that more than 250 million preschool children worldwide are vitamin A deficient.[39] Vitamin A deficiency is the leading cause of preventable blindness in children (Figure 18.13).Vitamin A deficiency depresses immune function, which increases the risk of infections; retards growth; and is often accompanied by anemia (see Chapter 9). In communities where vitamin A deficiency exists, supplementation has been shown to significantly reduce childhood deaths due to infection (see **Science Applied: Vitamin A: The Anti-Infective Vitamin**).

Obtaining sufficient vitamin A is a particular problem when needs are increased by rapid growth and development, such as during infancy, early childhood, and pregnancy. Need is also increased by frequent infections, such as measles and those causing diarrhea. Deficiencies of other nutrients, including fat, protein, and zinc, can contribute to vitamin A deficiency because they are needed to absorb and transport the vitamin in the body.

Other Nutrients of Concern In addition to deficiencies of protein, iron, iodine, and vitamin A, several other vitamin and mineral deficiencies have recently emerged or reemerged as problems throughout the world. Beriberi, pellagra, and scurvy, caused by deficiencies of thiamin, niacin, and vitamin C, respectively, are rare in the developed world but still occur among the extremely poor and underprivileged and in large refugee populations. Folate deficiency is also a problem in many parts of the world. It causes megaloblastic anemia during pregnancy and often compounds existing iron deficiency anemia. In women of childbearing age, low folate intake increases the risk of having a baby with a neural tube defect. In the United States, enriched grain products are fortified with folic acid to ensure adequate intake and to reduce the incidence of neural tube defects. The WHO recommends iron and folic acid supplementation for all menstruating women.[40]

Deficiencies of zinc, selenium, calcium, and vitamin D are also of concern.[41] It is estimated that over 17% of the world's population is at risk of inadequate zinc intake, with the highest prevalence in Sub-Saharan Africa and South Asia.[42] Zinc deficiency can cause growth retardation or failure, diarrhea, immune deficiencies, skin and eye lesions, delayed sexual maturation, night blindness, and behavioral changes. It may also contribute to intrauterine growth retardation and neural tube defects in the fetus, and in the elderly it may affect taste acuity and cause dermatitis and impaired immune function. Selenium deficiency is associated with an increased incidence of Keshan disease (see Chapter 12), a type of heart disease that affects mainly children and young women.[43] Inadequate calcium intake increases the risk of osteoporosis. Worldwide, one in three women and one in five men over age 50 will experience fractures due to osteoporosis.[44] During childhood, adolescence, and young adulthood, a diet adequate in calcium and vitamin D can help prevent osteoporosis by ensuring maximum peak bone density.

CDC

FIGURE 18.11 Hookworm infection
Hookworm larvae penetrate the skin, infecting people when they walk barefoot in contaminated soil. The parasites contribute to iron deficiency because they attach to the intestinal lining and feed on blood. Hookworm infection affects as many as 740 million people.[27]

LIFE CYCLE

© Mike Goldwater/Alamy Limited

FIGURE 18.12 Goiter
Goiter, which is an enlargement of the thyroid gland, is the most visible symptom of iodine deficiency.

ISM/Phototake

FIGURE 18.13 Xerophthalmia due to vitamin A deficiency
Vitamin A deficiency leads to xerophthalmia, shown here. It is estimated that 250,000 to 500,000 children go blind from vitamin A deficiency every year; half die within a year of losing their sight.[39]

SCIENCE APPLIED

Vitamin A: The Anti-Infective Vitamin

(Elena Schweitzer/ Shutterstock)

(www.victorianoizquierdo.com/ Getty Images, Inc.)

(DAJ/Getty Images, Inc.)

In 1910, one out of every four U.S. infants died before 1 year of age. The major causes were infectious diseases: epidemics of diarrhea during the summer and respiratory infections during the winter.[28] Similar problems affected children in Europe. In the early part of the 20th century, the discovery of vitamins led to observations that nutritional deficiency, particularly vitamin A deficiency, was associated with an increased incidence and severity of infectious disease.[29]

THE SCIENCE

In 1925, an epidemic of pneumonia swept through a colony of dogs in a research laboratory in England. The pneumonia occurred almost exclusively in vitamin A–deficient animals. It was hypothesized that the deficiency increased susceptibility to respiratory infections and that this might be relevant to infections in children.[30] Animal experiments confirmed this hypothesis, and vitamin A was dubbed the "anti-infective vitamin."[31]

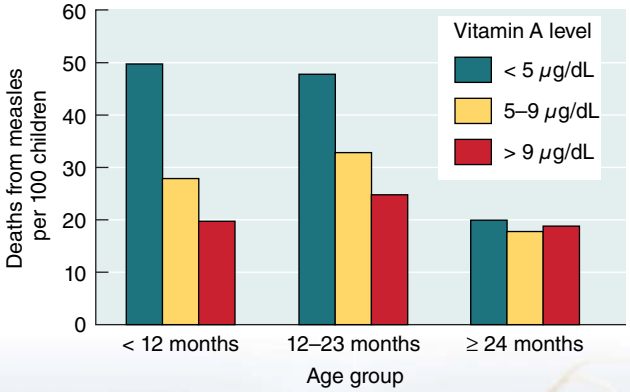
The theory that vitamin A could prevent infections triggered 20 years of clinical investigations. Clinical trials were conducted to determine if vitamin A, given as cod liver oil, could reduce morbidity and mortality from respiratory diseases, measles, and other infections. Although results were mixed, the pharmaceutical industry began promoting cod liver oil to decrease severity and recovery time in ailments such as whooping cough, measles, mumps, chickenpox, and scarlet fever.[28] The administration of cod liver oil became routine for millions of children in the United States and Europe in the 1940s.

In 1959, the World Health Organization (WHO) published a paper that reviewed the mounting evidence of a relationship between nutritional status and infection.[32] It recognized that poor nutritional status leads to more frequent and more severe infections, and infection triggers metabolic responses that cause nutrient losses. For example, a vitamin A deficiency reduces the ability of the immune system to defend itself against measles infection, and the infection itself causes loss of vitamin A that can precipitate acute vitamin A deficiency and blindness.[33] To a well-nourished child, measles is usually a passing illness, whereas to a malnourished child, it can result in lifelong disabilities or death (see graph).

THE APPLICATION

Today, antibiotics, vaccinations, and a nutritious and varied diet have reduced infant morbidity and mortality in the United States and other developed nations. Worldwide, though, infections are still responsible for about half of the deaths in children under age 5 every year, and about 45% of child deaths are associated with malnutrition.[2,6] Improved vitamin A status can help reduce the number of child deaths.

Before a vaccine was developed, measles claimed 7 to 8 million lives a year. It is estimated that between 2000 and 2013, measles vaccine prevented 15.6 million deaths.[35] Because of the interrelationship between vitamin A status and measles, the WHO and the United Nations Children's Fund (UNICEF) currently advise that large doses of vitamin A be provided to children with measles and that vitamin A be supplemented at the time of measles vaccination.[36] Providing vitamin A supplements is a short-term answer that can accompany long-term solutions to vitamin A deficiency and malnutrition, such as changes in dietary intake patterns and fortification of appropriate foods with vitamin A.



The relationship between vitamin A deficiency and death from measles is illustrated by this graph.[34] Children under 2 years of age with measles infections and very low serum vitamin A levels were twice as likely to die from the infection as children with higher levels.

18.3 Eliminating World Hunger

LEARNING OBJECTIVES

- Discuss two strategies that are used to reduce population growth.
- Explain how international trade can help eliminate hunger.
- Discuss the role of sustainable agriculture in maintaining the food supply.
- List three factors that should be considered when fortifying the food supply.

Solving the problem of world hunger is a daunting task. It involves eliminating poverty, controlling population growth, meeting the nutritional needs of a large and diverse population with culturally acceptable foods, increasing production of nutrient-dense foods, and maintaining the global ecosystem. It requires international cooperation, commitment from national and local governments, and the involvement of local populations. The solutions involve economic policies, technical advancement, education, and legislative measures. They require input from politicians, nutrition scientists, economists, and the food industry. Programs and policies must be in place to provide food in the short term, and in the long term establish sustainable programs to allow continued production and distribution of food.

Providing Short-Term Food Aid

When people are starving, short-term food and medical aid must be provided right away. The standard approach has been to bring food into the stricken area (Figure 18.14). The foods brought in generally consist of agricultural surpluses from other countries and often are not well planned in terms of their nutrient content. Although this type of relief is necessary for a population to survive an immediate crisis such as famine, it does little to prevent future hunger.

Many international, national, and private organizations are working toward the goal of relieving world hunger. The Food and Agriculture Organization (FAO) works to improve the production, intake, and distribution of food worldwide. The WHO targets community health centers and emphasizes the prevention of nutrition problems, such as micronutrient deficiencies. The World Bank finances projects such as nutrient supplementation and fortification to foster economic development. UNICEF, which relies on volunteer support, distributes food to all countries in need with a goal of assisting developing countries that occasionally suffer periods of starvation. The Red Cross, the UN Disaster Relief Organization, and the UN High Commissioner for Refugees concentrate on famine relief. The Peace Corps focuses more on fostering long-range development. More and more agencies are engaging in both development and relief. A few examples include the U.S. Agency for International Development, Oxfam, the Hunger Project, and Catholic Relief Services.

food security Access by all people at all times to sufficient food required for a healthy and active life.

Eliminating Poverty

Hunger will exist as long as there is poverty. Even when food is plentiful in a region, the poor do not have access to enough of the right foods to maintain their nutritional health. Economic development that guarantees safe and sanitary housing, access to health care and education, and the resources to acquire enough food are essential to eliminate hunger. Government policies can help to eliminate poverty by increasing the population's income, lowering food prices, or offering feeding programs for the poor, all of which can improve **food security**. International cooperation is also important in addressing hunger and poverty. The 193 member states of the United Nations (UN) recently adopted the Sustainable Development Goals, an agenda designed to

© AP/Wide World Photos

FIGURE 18.14 Emergency food relief
Many international relief organizations provide food to hungry people throughout the world.

FIGURE 18.15 2015 Sustainable Development Goals
Ending poverty and hunger are two of the 17 Sustainable Development Goals. These will continue the progress toward reducing poverty that was made by the Millennium Development Goals established in 1990.[46]

eradicate extreme poverty and tackle other areas of importance for humanity and the planet by 2030 (Figure 18.15).[45]

Providing Enough Food

In the long term, solving the problem of world hunger requires balancing the number of people with the amount of food available globally and locally. Inequities within populations must be addressed by eliminating poverty and providing opportunities for education—both to help people escape poverty and to teach them what constitutes a healthy diet and how to prepare it safely. Long-term solutions need to be based on the cultural and economic needs of the local population.

Controlling Population Growth The world's population has increased dramatically since the middle of the 20th century, but population growth has recently begun to slow. The fertility rate worldwide has declined—from 5 children per woman in 1950 to 2.5 today.[47] However, in developing countries, many women have more children than they desire. With increased access to and use of contraception, more women are able to delay and limit their fertility. To be successful, family-planning efforts must be acceptable to the population, compatible with their cultural and religious needs, and sustainable in the long term.

Population growth can also be reduced by increasing the level of education for women. Fertility rates decrease when the educational level increases (Figure 18.16).[48] Women with more education tend to marry later and have fewer children. Education also increases the likelihood that women will have control over their fertility, provides knowledge to improve family health, decreases infant and child mortality rates, and offers options other than having numerous children.

Food self-sufficiency
The ability of an area to produce enough food to feed its population.

Economic policies can also help reduce population growth. In some developing countries, higher fertility rates are due to the economic and societal roles of children. Children are needed to work the farms, support the elders, and otherwise contribute to the economic survival of the family. When infant mortality rates are high, people choose to have many children to ensure that some will survive. Programs that foster economic development and ensure access to food, shelter, and medical care have been shown to cause a decline in fertility rates because people feel secure having fewer children and because economic development reduces child mortality and the need for children as workers.

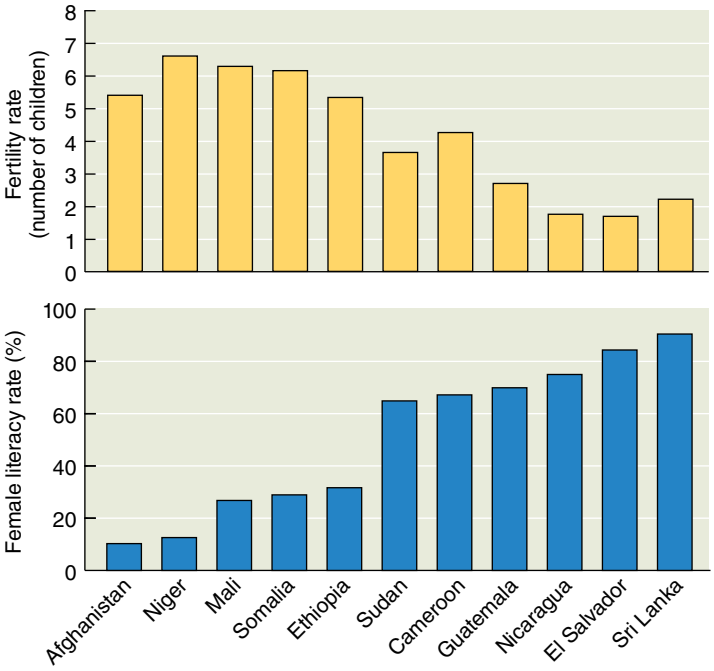


FIGURE 18.16 Education and fertility rates
The graphs show that higher literacy among women is associated with lower fertility rates.[3]

Producing and Importing Adequate Food **Food self-sufficiency** is a country's capacity to feed its population. Developing manageable systems for producing acceptable, sustainable sources of food can increase the level of food self-sufficiency. In countries with limited agricultural resources, imports can increase the food supply and help reduce hunger.

How Agricultural Technology Increases Food Production Technological advancements in agriculture can help a country boost food production. These include newer varieties of plants, better agricultural techniques, and improvements in irrigation. One type of technology being used to increase the quantity and improve the quality of food is genetic engineering (see Focus on Biotechnology). Crop yields can be increased either directly, by inserting genes that improve plant

growth, or indirectly, by creating plants that are resistant to herbicides, insects, and plant diseases, thus reducing crop losses. Genes that impart insect and herbicide resistance also help the environment because they allow farmers to reduce the insect damage to crops and minimize the number of weeds in fields with fewer insecticides and safer herbicides. Biotechnology can also be used to modify plant characteristics that are of importance after harvest, such as ease of transport, shelf life, and rate of ripening. The availability of older technologies such as freezing and refrigeration and better storage facilities can reduce food losses due to microbial spoilage, insects, and rodents and thus also increase the amount of food available to the population.

How International Trade Increases Food Availability Some countries have the resources to grow enough food to feed their population and others do not. When a country has few natural resources, access to international trade systems can help provide for their population. South Korea is an example of a country where an increase in food imports has helped feed the population. The mountainous terrain in South Korea means there is little arable land, and rice dominates areas where crops can be grown. Therefore, to increase food variety while keeping prices down, South Korea has turned to food imports. In general, the countries of the world are becoming more interdependent on food imports and on exports to pay for this food. This interdependence can increase the availability of food for the world population.

Whether a country's agricultural emphasis focuses on producing **subsistence crops** for local consumption or on producing **cash crops**, which can be sold on the national and international market, influences the availability of food for its people. Shifting to cash crops improves the cash flow of the country but uses local resources to produce crops for export and limits the ability of the local people to produce enough food to feed their families. For example, if a large portion of the arable land in West Africa is used to grow cash crops such as coffee and cotton, little agricultural land remains to grow grains and vegetables that nourish the local population. If, however, the cash from the crop is used to purchase nutritious foods for the local people, this decision may help alleviate undernutrition.

subsistence crop A crop that is grown as food for a farmer's family, with little or nothing left over to sell.

cash crop A crop that is grown to be sold for monetary return, rather than to feed the local population.

Maintaining the Environment The resources needed to support food production depend on the methods used. In developing nations, the resources used by a single person are small but the number of people is large, so it is difficult to produce sufficient food without depleting natural resources such as soil, forests, and water supplies. In developed nations, the population is less dense but the resource demands made by each individual are far greater because of lifestyles and the methods of food production and distribution. To allow continued food production for future generations, solutions to the problem of providing enough food must ensure that natural resources are conserved in both developing and industrialized nations.

Sustainable Agriculture **Sustainable agriculture** uses food production methods that prevent damage to the environment and allow the land to restore itself, so that food can be produced indefinitely. For example, contour plowing and terracing help prevent soil erosion, keeping the soil available for future crops. Rotating the crops grown in a specific field prevents the depletion of nutrients in the soil, reducing the need for added fertilizers. Sustainable agriculture uses environmentally friendly chemicals that degrade quickly and do not persist as residues in the environment. It also relies on diversification. This approach to farming maximizes natural methods of pest control and fertilization and protects farmers from changes in the marketplace (Figure 18.17).

sustainable agriculture Agricultural methods that maintain soil productivity and a healthy ecological balance while having minimal long-term impacts.

Sustainable agriculture is not a single program but involves choosing options that mesh well with the local soil, climate, and farming techniques. In some cases, organic farming, which does not use synthetic pesticides or fertilizers (see Chapter 17), may be the more sustainable option. Organic techniques have less environmental impact because they reduce the use of agricultural chemicals and the release of pollutants into the environment. Organic farming is also advantageous in terms of soil quality and biodiversity, but it is at a disadvantage when it comes to land use because crop yields are typically lower than with conventional farming.[49] A combination of organic and conventional techniques, as is used with integrated pest management (see Chapter 17), might be best for improving land use and protecting the environment.

Other sustainable programs include agroforestry, in which techniques from forestry and agriculture are used together to restore degraded areas; natural systems agriculture, which attempts to develop agricultural systems that include many types of plants and therefore function like natural ecosystems; and the technique of reducing fertilizer use by matching nutrient resources with the demands of the particular crop being grown.

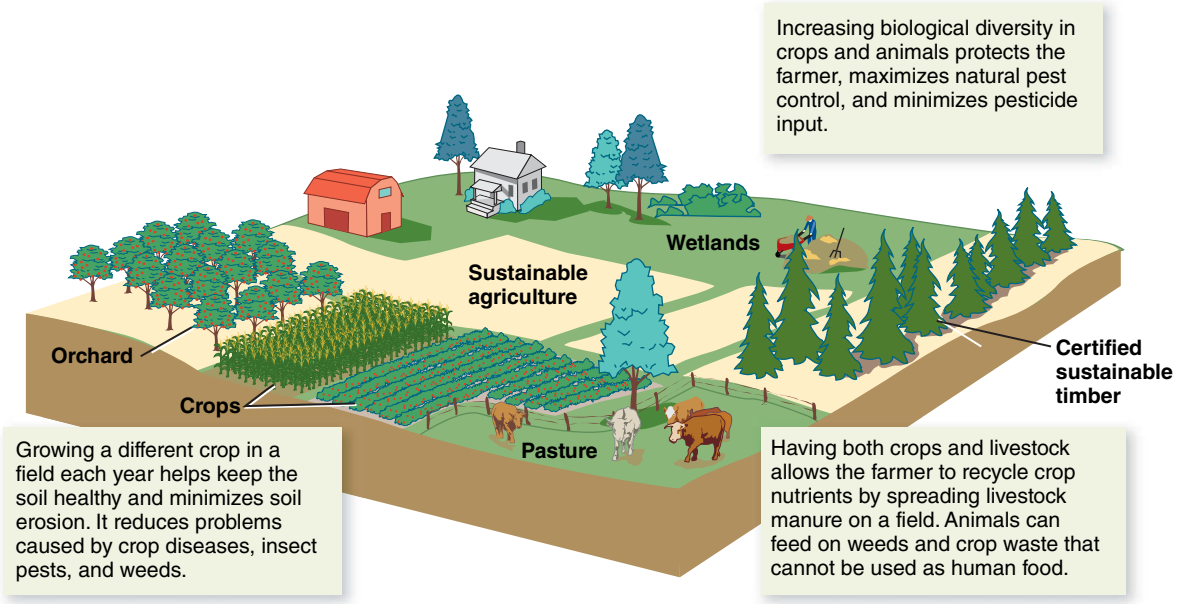


FIGURE 18.17 A sustainable farm
A sustainable farm consists of a total agricultural ecosystem rather than a single crop. It may include field crops, fruit- and nut-bearing trees, herds of livestock, and forests.

Sustainable Choices The choices individuals make can also influence the environmental impact of food production. Choosing a diet that is primarily plant based, with smaller amounts of animal products, can help to minimize the ecological impact of food production. Choosing locally grown foods in season can minimize the energy costs and pollution due to food transport. Choosing organically grown, minimally processed, and ecologically packaged foods can further reduce the environmental impact of food production (see **Critical Thinking: Can You Have an Impact?**).

Ensuring a Nutritious Food Supply

In addition to sufficient energy in the diet, the right mix of nutrients is necessary to ensure the nutritional health of a population. If the foods and crops that are grown or imported do not meet all nutrient needs, the quality of the diet will be poor and malnutrition will occur. Nutrient deficiencies can be addressed by changing dietary patterns, fortifying existing foods, or including dietary supplements. Genetic engineering can also address nutrient deficiencies by changing the nutrient content of foods (see Chapter 9, *Debate: Combating Vitamin A Deficiency with Golden Rice*).

How Food Fortification Alleviates Malnutrition Fortification is the process of adding one or more nutrients to commonly consumed foods with the goal of increasing the nutrient intake of a population. Food fortification will not provide energy to a hungry population, but it can increase the protein quality of the diet and eliminate micronutrient deficiencies. Fortification programs have been created by partnerships among industry, academia, and government. Industry and academia can provide the technology for adding nutrients to foods, and government public health policies can promote the consumption of these fortified foods.

In order for fortification to solve a nutritional problem in a population, it must be implemented wisely. Fortification works if vulnerable groups consume foods that are centrally processed. The foods selected for fortification should be among those consistently eaten by the majority of the population so that extensive promotion and reeducation are not needed to encourage their consumption. The nutrient should be added uniformly and in a form that optimizes its utilization. Fortification has been used successfully in preventing health problems in the United States: The fortification of cow's milk to increase vitamin D intake was a major factor in the elimination of infantile rickets, and the enrichment of grains with niacin helped eliminate

CRITICAL THINKING

Can You Have an Impact?

© Todd Bates/iStockphoto

Keesha is a college student concerned about the environment and problems of world hunger. Although she cannot afford to make monetary contributions to relief organizations, she would like her everyday choices to have a minimal impact on the environment. She eats a lot of salad but is not sure which of the options shown here is best.

Waltraud Ingerl/iStockphoto

Justin Sullivan/Getty Images, Inc.

The following are some inexpensive changes Keesha can make to reduce her impact on the environment:

- Bike instead of drive on short trips around town.
- Buy a canvas bag to carry groceries.
- Bring a water bottle rather than buying bottled water.
- Compost vegetable scraps.
- Buy locally grown produce.
- Buy organically grown produce.

Keesha likes fish but has heard that some fish are endangered. A few of her favorite varieties are listed below.

- Atlantic cod
- Chilean sea bass
- Orange roughy

Use the Internet to find some ocean-friendly substitutes for Keesha's seafood favorites.

CRITICAL THINKING QUESTIONS

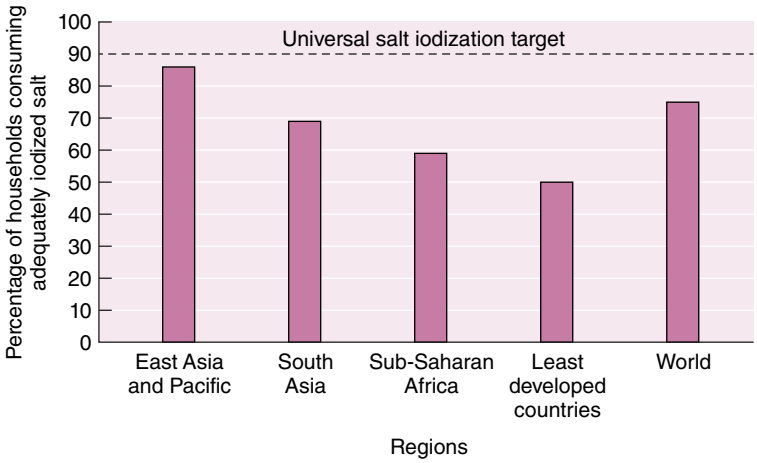
- **List one advantage and one disadvantage in terms of convenience, of food safety, and of environmental impact, for the packaged salad and for the fresh produce.**
- **List one advantage and one disadvantage for each of Keesha's changes.**

iProfile Use iProfile to lookup the omega-3 fatty acid content of your favorite sustainable seafood.

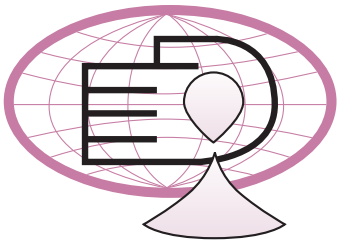
pellagra. The most recent program is the fortification of grains with folic acid to reduce neural tube defects in newborns (see Chapters 8 and 14).

Fortification has also been used successfully in developing countries. For the past 30 years, universal salt iodization has been the most widely used strategy to control and eliminate iodine deficiency disorders. In 1990, the United Nations World Summit for Children established the goal of eliminating iodine deficiency worldwide. In 1993, global iodization of salt was recommended by the International Council for Control of Iodine Deficiency Disorders; the target is consumption of adequately iodized salt in more than 90% of households. This target has not yet

FIGURE 18.18 Increasing access to Iodized salt



A. Universal salt iodization programs have increased worldwide access to iodized salt from about 20% of households in 1990 to about 75% today.[50,51]



B. The global iodized salt logo is used around the world as an indicator of iodized salt.

been reached, but salt iodization has dramatically increased the availability of iodine around the world (Figure 18.18).

How Supplementation Is Used to Eliminate Malnutrition Supplementing specific nutrients for at-risk segments of the population can also help reduce the prevalence of micronutrient deficiencies. For example, supplementation of vitamin A has been found to be a low-cost, highly effective means of improving vitamin A status of children—it is the quickest intervention to implement on a national scale.[52] Of countries where vitamin A deficiency is a public health problem, about three-fourths have policies supporting regular vitamin A supplementation in children. Many have also adopted the WHO recommendation to provide all breast-feeding women with a high-dose supplement of vitamin A within 8 weeks of delivery. This improves maternal vitamin A status and increases the amount of vitamin A that is in breast milk, and therefore passed to the infant. Many countries have adopted programs to supplement children older than 6 months of age with iron and pregnant women with iron and folate.

Providing Education

Education can help improve nutrient intake by teaching consumers which foods are good nutrient sources, so that choices made when purchasing foods or growing vegetables at home can meet nutrient needs. Education about how to prepare foods safely is also critical so food-borne illness doesn't compromise nutritional and overall health. Policies to reduce micronutrient deficiencies also need to include education and strategies to control other infectious and parasitic diseases.

Education is particularly important when introducing a new crop. No matter how nutritious, a new plant variety is not beneficial unless local farmers know how to grow it and the population accepts it as part of their diet and knows how to prepare it. For instance, white yams are common in some regions but are a poor source of β-carotene, which the body can use to make vitamin A. If sweet potatoes, which are rich in β-carotene, became an acceptable choice, the vitamin A available to the population would increase (Figure 18.19). Food safety is also a concern when changing traditional dietary practices. For example, introducing papaya to the diet as a source of vitamin A will not improve nutritional status if the fruit is washed in unsanitary water and causes dysentery among the people it is meant to nourish.

© YinYang/iStockphoto

FIGURE 18.19 Sweet potatoes
Replacing yams, which are a poor source of β-carotene, with sweet potatoes, which contain enough β-carotene to meet the requirement for vitamin A in a single serving, can improve the quality of the diet.

THINK CRITICALLY

What steps would you suggest to convince a population to replace white yams with sweet potatoes?

Education to encourage breast-feeding can also improve nutritional status and health. Breast-feeding reduces the risk of infectious diseases in infants. When infants are not breast-fed, education about nutritious breast milk substitutes and their safe preparation is essential.

18.4 Hunger at Home

LEARNING OBJECTIVES

- Discuss the causes of food insecurity in the United States.
- Describe factors that prevent people from escaping poverty.
- List the population groups at greatest risk for undernutrition in the United States.
- Describe five federal programs designed to alleviate hunger in the United States.

In the United States, most of the nutritional problems are related to overnutrition. Over 68% of adults in the United States are overweight or obese.[53] Heart disease, hypertension, and cancer—all related to obesity—are the leading causes of death. While much of the population is concerned with consuming a diet to lower the risks for these chronic diseases, hungry families are standing in line at soup kitchens. Problems such as poverty and unemployment lead to food insecurity in a land of plenty. Government food and nutrition policy must be concerned with improving economic security as well as providing food to the hungry and maintaining the food supply at an affordable level—and at the same time, that policy must promote healthy diets to reduce diseases related to overconsumption.

Causes of Food Insecurity

In the United States, general food shortage is not the cause of undernutrition, but food insecurity, hunger, and undernutrition are growing problems. Today, about 17.5 million American households experience food insecurity due to a lack of money or other resources (Figure 18.20).[54] About 6.8 million households, including 3.8 million households with children, experience very low food security. This means that food intake is reduced in one or more household members. Over time, this can lead to malnutrition. The incidence of hunger and food insecurity is higher among the poor; the homeless; women, infants, and children; and the elderly; but illness, disability, a sudden decrease in income, or an increase in living expenses can put anyone at risk for food insecurity.

Poverty Poverty, the main cause of food insecurity, reduces access to food, education, and health care. About 14.5% of Americans (45.3 million people) live at or below the poverty level

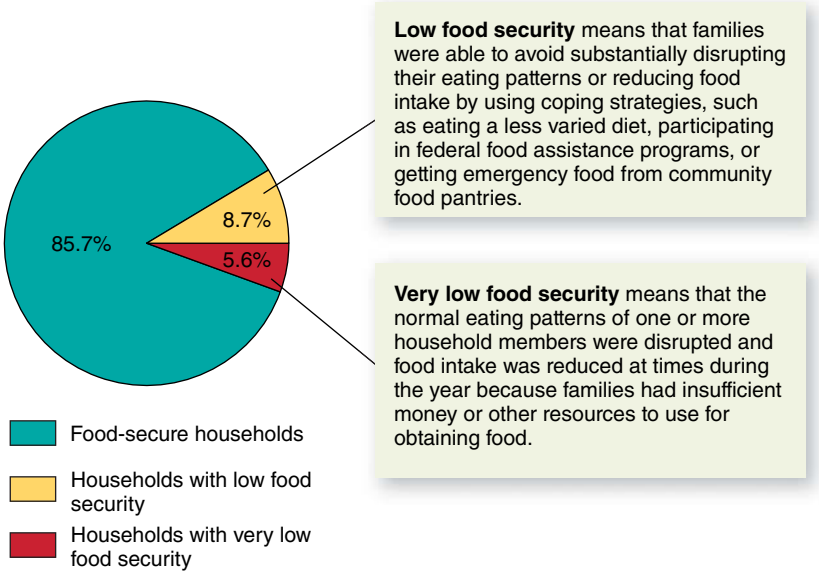


FIGURE 18.20 Food insecurity in the United States
In 2013, approximately 85.7% of U.S. households were food secure; the other 14.3% experienced food insecurity at some point during the year.[54]

2015 Poverty Guidelines*

Persons in family/household	Poverty guideline (dollars/year)
1	$11,770
2	$15,930
3	$20,090
4	$24,250
5	$28,410
6	$32,570
7	$36,730
8	$40,890

For families/households with more than 8 persons, add $3,960 for each additional person.

*Includes the 48 contiguous states and the District of Columbia

Urban food desert

Richard B. Levine/Newscom

Rural food desert

Clay Peterson/The Californian/©AP/Wide World Photos

FIGURE 18.21 Poverty and food deserts
In the United States, 23.5 million people live in food deserts where they have limited access to affordable nutritious food; more than half have low incomes.[58] These deserts can be in cities, where high prices make healthy foods inaccessible to the poor, or in rural areas, where healthy food can be inaccessible because the nearest grocery store may be 40 miles away.

(Figure 18.21).[55] High poverty and unemployment rates among Native Americans and Alaska Natives contribute to food insecurity.[56] The poor have less money to spend on food and often have less access to affordable food. The high price of real estate in cities has driven supermarkets into the suburbs, and because many low-income city families do not own cars, they must shop at small, expensive corner stores or pay cab fares if they wish to take advantage of lower prices at more distant, larger stores. The rural poor may have limited access to food because they live far from grocery stores. For example, migrant workers have limited access to food because labor camps are in remote locations and transportation is often unavailable. Low incomes and difficult working and living conditions among migrant workers further limit their ability to purchase food and prepare adequate meals. The lack of access to fresh, healthy, affordable food in many urban neighborhoods and rural towns results in what are called **food deserts** (see Figure 18.21).[57]

food desert An area that lacks access to affordable fruits, vegetables, whole grains, low-fat milk, and other foods that make up a healthy diet.

Lack of Education Lack of education, which is both a cause and a consequence of poverty, also contributes to food insecurity (Figure 18.22). For people at or below the poverty level, educational opportunities are fewer and lower in quality than those for people with higher incomes. In the short term, lack of knowledge about food selection, food safety, and home economics can contribute to malnutrition. Too little food may make the diet deficient in energy or particular nutrients, but poor food choices also allow food insecurity to coexist with obesity. Lack of education about food safety can also increase the incidence of food-borne illness. In the long term, lack of education prevents people from getting the higher-paying jobs that could allow them to escape poverty.

Limited Health Care Poverty also limits access to health care, leading to poorer health status. Iron deficiency is more than twice as frequent in low-income children, and the incidence of heart disease, cancer, hypertension, and obesity increases with decreasing income. As in developing nations, poverty is reflected in infant mortality rates. Average infant mortality in the U.S. population is about 6 per 1000 live births. However, there are groups within the population that have infant mortality rates as high as those in impoverished nations. Among African Americans, the infant mortality rate is 11.5 per 1000 live births—almost double that of the overall population.[60] This difference mirrors the higher poverty rate in this group.

Homelessness The poor must use most of their income to pay for shelter, which seriously reduces the chances that their families will be adequately fed. The high cost of housing not only limits food budgets but also has created a growing problem of homelessness in the United States. It is estimated that over 610,000 Americans are homeless.[61] Many homeless people live in shelters, but others must live in unsheltered locations such as abandoned buildings, under bridges, or in

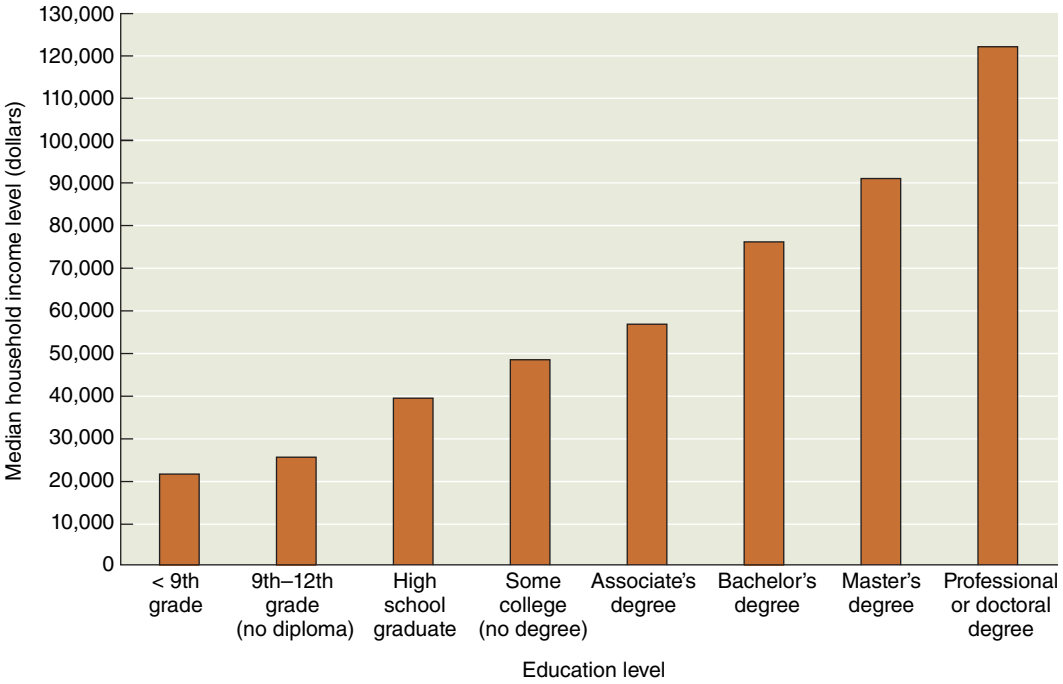


FIGURE 18.22 Education increases income[59]
Income level in the United States is directly correlated with level of education.

ANALYZE THE DATA

Compared to someone with a high school diploma, how much more on average will someone with a bachelor's degree earn?

their cars. People who are homeless are at high risk of malnutrition and food insecurity because they lack not only money but also cooking and food-storage facilities. Without cooking facilities, they must rely on ready-to-eat foods. Without storage facilities, they cannot use less expensive staples such as rice and dried beans, which can be purchased in bulk. Homeless individuals often rely on soup kitchens and shelters to obtain adequate food.

A Cycle of Poverty Many Americans find themselves trapped in a cycle of poverty (Figure 18.23). As the U.S. economy has shifted from manufacturing to service-based jobs, factories have closed and manufacturing facilities have moved abroad, where labor costs are lower. Former employees often lack the experience or education to move on to other types of work. Unable to find well-paying jobs, they must work longer hours at lower-paying jobs. Low incomes reduce access to transportation and child care, which can also limit access to better jobs. Long work hours reduce the amount of time available to pursue the additional education or training necessary to find better-paying jobs. Limited income and transportation prohibit relocation to areas where better jobs are available.

LIFE CYCLE

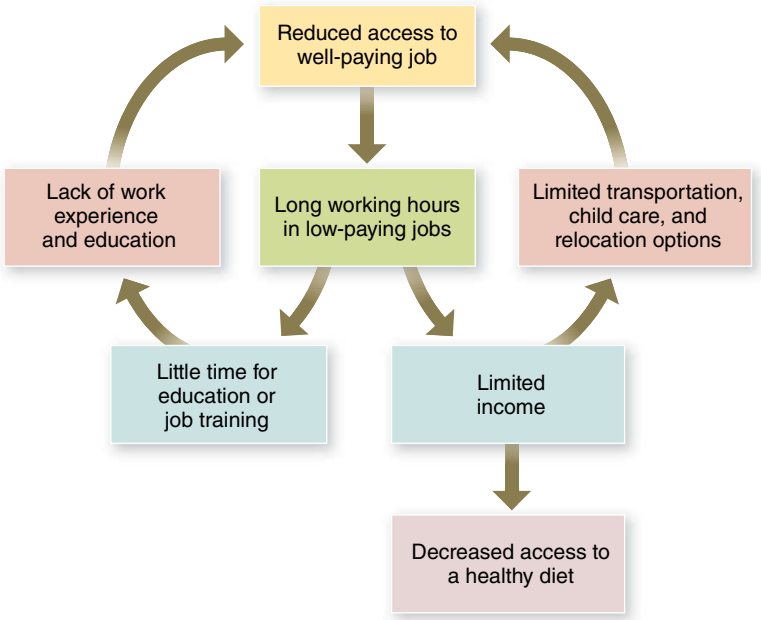


FIGURE 18.23 A cycle of poverty
Some Americans are trapped in a cycle of poverty because they are unable to acquire the education, training, or resources necessary to obtain better-paying jobs.

High Nutrient Needs The high nutrient needs of pregnant and lactating women and small children put them at particular risk for undernutrition. One out of four households with children headed by single women lives below the poverty line.[62] Poverty and food insecurity place these women and children at risk of malnutrition, and their special nutritional needs magnify this risk. Because of their increased need for some nutrients, malnutrition may occur in pregnant women, infants, and children even when the rest of the household is adequately fed. For example, the amount of iron in the family diet may be enough to prevent anemia in all but a pregnant teenager.

TABLE 18.3 Programs to Prevent Undernutrition in the United States

Program	Target population	Goals and methods
Supplemental Nutrition Assistance Program (SNAP)	Low-income individuals	Increases access to food by providing coupons or debit cards that can be used to purchase food at a grocery store
Commodity Supplemental Food Program (CSFP)	Low-income pregnant women, breast-feeding and non–breast-feeding postpartum women, infants and children under age 6, and elderly people	Provides food by distributing USDA commodity foods
Special Supplemental Nutrition Program for Women, Infants, and Children (WIC)	Low-income pregnant women, breast-feeding and non–breast-feeding postpartum women, and infants and children under age 5	Provides vouchers for the purchase of foods (including infant formula and infant cereal) high in nutrients that are typically lacking in the program's target population; provides nutrition education and referrals for health care
WIC Farmers' Market Nutrition Program	WIC participants	Increases access to fresh produce by providing vouchers that can be used to purchase produce at authorized local farmers' markets
School Breakfast Program	Low-income school-age children	Provides free or low-cost breakfasts at school to improve the nutritional status of children
National School Lunch Program	Low-income school-age children	Provides free or low-cost lunches at school to improve the nutritional status of children
Special Milk Program	Low-income school-age children	Provides milk for children in schools, camps, and child-care institutions with no federally supported meal program
Summer Food Service Program	Low-income school-age children	Provides free meals and snacks for children when school is not in session
Child and Adult Care Food Program	Children up to age 12, older adults, and adults with disabilities	Provides nutritious meals to children and adults in day-care settings
Team Nutrition	School-age children	Provides nutrition education, training and technical assistance, and resources to participating schools, with the goal of improving children's lifelong eating and physical activity habits
Head Start	Low-income preschool children and their families	Provides meals and education, including nutrition education
Nutrition Program for the Elderly	Individuals ages 60 and over and their spouses	Provides free congregate meals in churches, schools, senior centers, or other facilities and delivers food to homebound people
Senior Farmers' Market Program	Low-income seniors	Provides coupons that can be exchanged for eligible foods at farmers' markets, roadside stands, and community-supported agricultural programs
Homeless Children Nutrition Program	Preschoolers living in shelters	Reimburses providers for meals served
Emergency Food Assistance Program	Low-income people	Provides commodities to soup kitchens, food banks, and individuals for home use
Healthy People 2020	U.S. population	Sets national health promotion objectives to improve the health of the U.S. population through health-care system and industry involvement, as well as individual actions
Expanded Food and Nutrition Education Program (EFNEP)	Low-income families	Provides education in all aspects of food preparation and nutrition
Temporary Assistance for Needy Families (TANF)	Low-income households	Provides assistance and work opportunities to needy families by granting states federal funds to implement welfare programs
Food Distribution Program on Indian Reservations	Low-income households living on reservations and Native Americans living near reservations	Provides food by distributing USDA commodity foods

Disease and Disability Diseases and disabilities limit the ability to purchase, prepare, and physically ingest food. These conditions are more common in the elderly, especially those who are poor, putting them at risk for malnutrition. Greater nutritional risk among older adults is associated with more hospital admissions, and hence greater health-care costs. The number of individuals over age 85 is expected to quadruple by the year 2050; as the number of elderly increases, so will the number at risk of food insecurity.[63] Thus, providing food security for older adults both improves their quality of life and reduces costs for the public health-care system (see Chapter 16).

Federal Programs to Prevent Malnutrition

Solving the problem of undernutrition in the United States involves improving economic security, keeping food affordable, providing food aid to the hungry, and offering education about healthy diets that will meet nutrient needs and reduce diseases related to overconsumption. Historically, many approaches have been attempted to reach this goal. Some have met with success and others have done little to increase access to a nutritious diet for all. Programs that provide access to affordable food and promote healthy eating have been referred to as a *nutrition safety net* for the American population.

The Nutrition Safety Net The nutrition assistance programs in the United States include a combination of general nutrition assistance and specialized programs targeted to groups with particular nutritional risks: children, older adults, infants, women during and after pregnancy, Native Americans living on reservations, people with disabilities, and homeless people (Table 18.3). One of every four Americans receives some kind of food assistance, at a total cost of about $103.6 billion per year.[64]

The largest USDA program designed to make sure that all people have access to an adequate diet is the Supplemental Nutrition Assistance Program (SNAP) (previously known as the Food Stamp Program). SNAP provides monthly benefits in the form of coupons or debit cards that can be used to purchase food, thereby supplementing the food budgets of low-income individuals. Together with SNAP, four other programs that target high-risk populations—the National School Lunch Program, the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), the Child and Adult Care Food Program, and the School Breakfast Program—account for 96% of the USDA's expenditure for food assistance.[65]

In addition to federal nutrition assistance programs, church, community, and charitable emergency food shelters provide for the basic nutritional needs of many Americans. In the United States, about 150,000 nonprofit food distribution programs help direct food to those in need. The leading hunger-relief charity in the United States is Feeding America, which provides food assistance to over 46 million low-income people per year.[66] It includes a network of food banks across the country and supports thousands of local charitable organizations, such as food pantries and soup kitchens, which distribute food directly to hungry Americans.

Virtually all these food distribution programs use food obtained through **food recovery**, which involves collecting food that is wasted in fields, commercial kitchens, restaurants, and grocery stores and distributing it to those in need (Figure 18.24). It is estimated that over 40% of America's food—equivalent to $165 billion—goes to waste each year.[67]

food recovery The collection of wholesome food for distribution to the poor and hungry, including collection of crops from farmers' fields that have already been mechanically harvested or from fields where it is not economically profitable to harvest.

© Damian Dovarganes/© AP/Wide World Photos

FIGURE 18.24 Field gleaning
These oranges were harvested in California as part of a local gleaning program. Field gleaning is a type of food recovery that involves collecting crops that are not harvested because it is not economically profitable to harvest them or that remain in fields after mechanical harvesting.

Providing Nutrition Education The link between nutrition education and diet quality is strong. People with more nutrition information and more awareness of the relationship between diet and health consume healthier diets.[68] Healthy diets not only improve current health by optimizing growth, productivity, and well-being, but are essential for preventing chronic diseases in the future. Increasing nutrition knowledge can reduce medical care costs and improve the quality of life.

Education can help individuals with lower incomes stretch limited food dollars by making wise choices at the store and reducing food waste at home. Education can promote community gardens to increase the availability of seasonal vegetables. It can teach people how to prepare foods that become available through commodity distribution and food banks. It can explain safe food handling and food preparation methods. Knowing which foods to choose and how to handle them safely is as important in preventing malnutrition as having the money to buy enough food.

A number of government programs are designed to provide nutrition education. One of the goals of Healthy People 2020 is to increase the nutrition education provided by schools as well as by work sites. The Expanded Food and Nutrition Education Program (EFNEP) provides education in all aspects of food preparation and nutrition to low-income families. In addition, the *Dietary Guidelines for Americans*, MyPlate, and standardized food labels educate the general public about making wise food choices.

OUTCOME

When Teresa joined the Peace Corps, she quickly saw the huge effect malnutrition and infectious diseases were having on the health of children in Rwanda and around the world. Meeting Songe introduced her to the impact of and treatment for protein-energy malnutrition (PEM). After a few months of consuming the high-protein supplement, Songe's belly shrank and his arms and legs began filling out with muscle. Because his malnutrition was treated early, Songe is now a healthy, playful 3-year-old. Others are not as lucky. Many children with short stature due to malnutrition also have cognitive delays that impair their education and job potential throughout their lives. Teresa has seen children with severe anemia from iron deficiency and those who have lost their eyesight due to the complications of vitamin A deficiency. Some children are so ill by the time they reach the clinic that they cannot be saved.

While in the Peace Corps, Teresa helped educate families about the right combinations of foods needed to prevent malnutrition as well as the importance of clean water and hygiene to prevent infections. She learned all she could about the foods available locally so she could recommend meals that provide the nutrients that are at risk of deficiency in the population. **Teresa's suggestions helped, but she recognized that the limited local diet and the high incidence of infectious diseases in the population meant she would continue to see young children with protein and micronutrient deficiencies.**

SUMMARY

18.1 The Two Faces of Malnutrition

- In poorly nourished populations, a cycle of undernutrition exists in which undernourished women give birth to low-birth-weight infants at risk of disease and early death. Children who survive grow poorly and become adults who are physically unable to contribute fully to society. Undernutrition in children causes stunting. The prevalence of stunting is used as an indicator of nutritional well-being in populations of children. Undernutrition depresses immune function at all stages of life, causing an increase in the frequency and severity of infectious diseases.
- Overnutrition is now a global health problem that affects as many people as undernutrition. Rising obesity rates increase the

incidence of chronic diseases such as cardiovascular disease and type 2 diabetes worldwide. Obesity now coexists with undernutrition in both developed and developing nations around the world.

- Changes in diet and lifestyle occur as economic conditions in a country improve. Traditional rural diets that contribute to undernutrition are replaced by Western-style diets that increase the risk of overnutrition.

18.2 Causes of Hunger and Undernutrition

- World hunger exists due to the inequitable distribution of available food. Natural and man-made disasters can temporarily disrupt food production and distribution and cause famine.
- Chronic food shortage occurs when economic inequities result in lack of money, health care, and education for individuals or populations; when overpopulation and limited natural resources create a situation in which there are more people than food; when cultural practices limit food choices; and when environmental resources are misused, limiting the ability to continue to produce food.
- Go to WileyPLUS to view a video clip on famine in Ethiopia.

- Malnutrition occurs when the quality of the diet is poor. High-risk groups with special nutrient needs, such as pregnant women, children, the elderly, and the ill, may not be able to meet their nutrient needs with the available diet. Deficiencies of protein, iron, iodine, vitamin A, and zinc are common worldwide.

18.3 Eliminating World Hunger

- Short-term solutions to undernutrition provide food through relief at the local, national, and international levels.
- Long-term solutions to undernutrition must ensure the availability of food by improving economic conditions to eliminate poverty, controlling population growth, increasing the food supply through agricultural technology or importation, and developing sustainable systems that provide food without damaging the environment.
- Long-term solutions to undernutrition must ensure a nutritionally adequate food supply. Food fortification and dietary supplementation can be used to increase protein quality and eliminate micronutrient deficiencies and improve the overall quality of the diet.
- Education about what to eat and how to prepare food safely can help eliminate malnutrition.

18.4 Hunger at Home

- Both undernutrition and overnutrition are problems in the United States. Food insecurity is associated with poverty, which limits education and access to health care and adequate housing. High nutrient needs increase the risk of malnutrition in women and children, and disease and disability increase risk in the elderly. Food deserts limit access to food in certain segments of the population.
- Nutrition programs in the United States focus on maintaining a nutrition safety net that will provide access to affordable food and promote healthy eating. Some programs designed to help feed the hungry address the general population, whereas others focus on specific high-risk groups. Most programs provide access to food and some provide nutrition education.

Appendix A

Additional DRI Tables

DRI tables for Macronutrients, Energy, Vitamins, and Minerals are located following the Index in this text.

Dietary Reference Intake Values for Energy: Total Energy Expenditure (TEE) Equations for Overweight and Obese Individuals

Life Stage Group	*TEE Prediction Equation(Cal/day)*	*PA Values*
Overweight boys ages 3–18 years	TEE = 114 − (50.9 × age in yrs) + PA[(19.5 × weight in kg) + (1161.4 × height in m)]	Sedentary = 1.00 Low active = 1.12 Active = 1.24 Very active = 1.45
Overweight girls ages 3–18 years	TEE = 389 − (41.2 × age in yrs) + PA[(15.0 × weight in kg) + (701.6 × height in m)]	Sedentary = 1.00 Low active = 1.18 Active = 1.35 Very active = 1.60
Overweight and obese men ages 19 years and older	TEE = 1086 − (10.1 × age in yrs) + PA[(13.7 × weight in kg) + (416 × height in m)]	Sedentary = 1.00 Low active = 1.12 Active = 1.29 Very active = 1.59
Overweight and obese women ages 19 years and older	TEE = 448 − (7.95 × age in yrs) + PA[(11.4 × weight in kg) + (619 × height in m)]	Sedentary = 1.00 Low active = 1.16 Active = 1.27 Very active = 1.44

Source: Institute of Medicine, Food and Nutrition Board, "Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids," Washington, D.C.: National Academy Press, 2002, 2005.

Dietary Reference Intakes: Recommended Intakes for Individuals: Indispensable Amino Acids

Amino Acid	*Adults 19 years and older* *mg/kg/day*	*Pregnancy (all ages)* *mg/kg/day*	*Lactation (all ages)* *mg/kg/day*
Histidine	14	18	19
Isoleucine	19	25	30
Leucine	42	56	62
Lysine	38	51	52
Methionine + Cysteine	19	25	26
Phenylalanine + Tyrosine	33	44	51
Threonine	20	26	30
Tryptophan	5	7	9
Valine	4	31	35

Source: Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Protein and Amino Acids*. Washington, DC: National Academies Press, 2002.

Appendix B

Other Government Recommendations

USDA Food Patterns

For each food group or subgroup,[a] recommended average daily intake amounts[b] at all calorie levels. Recommended intakes from vegetable and protein foods subgroups are per week. For more information and tools for application, go to MyPlate.gov.

Calorie level of pattern	1,000	1,200	1,400	1,600	1,800	2,000	2,200	2,400	2,600	2,800	3,000	3,200
Fruits	1 c	1 c	1½ c	1½ c	1½ c	2 c	2 c	2 c	2 c	2½ c	2½ c	2½ c
Vegetables	1 c	1½ c	1½ c	2 c	2½ c	2½ c	3 c	3 c	3½ c	3½ c	4 c	4 c
Dark-green vegetables	½ c/wk	1 c/wk	1 c/wk	1½ c/wk	1½ c/wk	1½ c/wk	2 c/wk	2 c/wk	2½ c/wk	2½ c/wk	2½ c/wk	2½ c/wk
Red and orange vegetables	2½ c/wk	3 c/wk	3 c/wk	4 c/wk	5½ c/wk	5½ c/wk	6 c/wk	6 c/wk	7 c/wk	7 c/wk	7½ c/wk	7½ c/wk
Beans and peas (legumes)	½ c/wk	½ c/wk	½ c/wk	1 c/wk	1½ c/wk	1½ c/wk	2 c/wk	2 c/wk	2½ c/wk	2½ c/wk	3 c/wk	3 c/wk
Starchy vegetables	2 c/wk	3½ c/wk	3½ c/wk	4 c/wk	5 c/wk	5 c/wk	6 c/wk	6 c/wk	7 c/wk	7 c/wk	8 c/wk	8 c/wk
Other vegetables	1½ c/wk	2½ c/wk	2½ c/wk	3½ c/wk	4 c/wk	4 c/wk	5 c/wk	5 c/wk	5½c/wk	5½ c/wk	7 c/wk	7 c/wk
Grains	3 oz-eq	4 oz-eq	5 oz-eq	5 oz-eq	6 oz-eq	6 oz-eq	7 oz-eq	8 oz-eq	9 oz-eq	10 oz-eq	10 oz-eq	10 oz-eq
Whole grains	1½ oz-eq	2 oz-eq	2½ oz-eq	3 oz-eq	3 oz-eq	3 oz-eq	3½ oz-eq	4 oz-eq	4½ oz-eq	5 oz-eq	5 oz-eq	5 oz-eq
Enriched grains	1½ oz-eq	2 oz-eq	2½ oz-eq	2 oz-eq	3 oz-eq	3 oz-eq	3½ oz-eq	4 oz-eq	4½ oz-eq	5 oz-eq	5 oz-eq	5 oz-eq
Protein foods	2 oz-eq	3 oz-eq	4 oz-eq	5 oz-eq	5 oz-eq	5½ oz-eq	6 oz-eq	6½ oz-eq	6½ oz-eq	7 oz-eq	7 oz-eq	7 oz-eq
Seafood	3 oz/wk	5 oz/wk	6 oz/wk	8 oz/wk	8 oz/wk	8 oz/wk	9 oz/wk	10 oz/wk	10 oz/wk	11 oz/wk	11 oz/wk	11 oz/wk
Meat, poultry, eggs	10 oz/wk	14 oz/wk	19 oz/wk	24 oz/wk	24 oz/wk	26 oz/wk	29 oz/wk	31 oz/wk	31 oz/wk	34 oz/wk	34 oz/wk	34 oz/wk
Nuts, seeds, soy products	1 oz/wk	2 oz/wk	3 oz/wk	4 oz/wk	4 oz/wk	4 oz/wk	4 oz/wk	5 oz/wk	5 oz/wk	5 oz/wk	5 oz/wk	5 oz/wk
Dairy	2 c	2½ c	2½ c	3 c	3 c	3 c	3 c	3 c	3 c	3 c	3 c	3 c
Oils	15 g	17 g	17 g	22 g	24 g	27 g	29 g	31 g	34 g	36 g	44 g	51 g
Limit on calories from SoFAS[c]	137 (14%)	121 (10%)	121 (9%)	121 (8%)	161 (9%)	258 (13%)	266 (12%)	330 (14%)	362 (14%)	395 (14%)	459 (15%)	596 (19%)

[a]All foods are assumed to be in nutrient-dense forms, lean or low-fat and prepared without added fats, sugars, or salt. Solid fats and added sugars may be included up to the daily maximum limit identified in the table.

[b]Food group amounts are shown in cup- (c) or ounce-equivalents (oz-eq). Oils are shown in grams (g). Quantity equivalents for each food group are:

- Grains, 1 ounce-equivalent is 1 one-ounce slice bread; 1 ounce uncooked pasta or rice: ½ cup cooked rice, pasta, or cereal; 1 tortilla (6" diameter); 1 pancake (5" diameter); 1 ounce ready-to-eat cereal (about 1 cup cereal flakes).
- Vegetables and fruits, 1 cup equivalent is: 1 cup raw or cooked vegetable or fruit; ½ cup dried vegetable or fruit; 1 cup vegetable or fruit juice; 2 cups leafy salad greens.
- Protein foods, 1 ounce-equivalent is: 1 ounce lean meat, poultry, seafood; 1 egg; 1 Tbsp peanut butter; ½ ounce nuts or seeds. Also, ¼ cup cooked beans or peas may also be counted as 1 ounce-equivalent.
- Dairy, 1 cup-equivalent is: 1 cup milk, fortified soy beverage, or yogurt; 1½ ounce natural cheese (e.g., cheddar); 2 ounces of processed cheese.

[c]SoFAS are calories from solid fats and added sugars. The limit for SoFAS is the remaining amount of calories in each food pattern after selecting the specified amount in each food group in nutrient-dense forms (forms that are fat-free or low-fat and with no added sugars). The number of SoFAS is lower in the 1,200, 1,400, and 1,600 calorie patterns than in the 1,000 calorie pattern. The nutrient goals for the 1,200 to 1,600 calorie patterns are higher and require that more calories be used for nutrient-dense foods from the food groups.

DASH Eating Plan—Number of Food Servings by Calorie Level

Food Group	Servings per Calorie level						
Calories (kcal)	1,200	1,400	1,600	1,800	2,000	2,600	3,100
Grains[a]	4–5	5–6	6	6	6–8	10–11	12–13
Vegetables	3–4	3–4	3–4	4–5	4–5	5–6	6
Fruits	3–4	4	4	4–5	4–5	5–6	6
Fat-free or low-fat dairy products[b]	2–3	2–3	2–3	2–3	2–3	3	3–4
Lean meats, poultry, and fish	3 or less	3–4 or less	3–4 or less	6 or less	6 or less	6 or less	6–9
Nuts, seeds, and legumes	3 per week	3 per week	3–4 per week	4 per week	4–5 per week	1	1
Fats and oils[c]	1	1	2	2–3	2–3	3	4
Sweets and added sugars	3 or less per week	3 or less per week	3 or less per week	5 or less per week	5 or less per week	<2	<2
Maximum sodium limit[d]	2,300 mg/day	2,300 mg/day	2,300 mg/day	2,300 mg/day	2,300 mg/day	2,300 mg/day	2,300 mg/day

[a]Whole grains are recommended for most grain servings as a good source of fiber and nutrients.

[b]For lactose intolerance, try either lactase enzyme pills with dairy products or lactose-free or lactose-reduced milk.

[c]Fat content changes the serving amount for fats and oils. For example, 1 Tbsp regular salad dressing = one serving; 1 Tbsp low-fat dressing = one-half serving; 1 Tbsp fat-free dressing = zero servings.

[d]The DASH eating plan has a sodium limit of either 2,300 mg or 1,500 mg per day.

Source: National Institutes of Health. National Heart, Lung and Blood Institute. Following the DASH Eating Plan. Available online at http://www.nhlbi.nih.gov/health/health-topics/topics/dash/followdash

Recommended Dietary Intakes (RDIs)*

Vitamins and Minerals	*Units of Measurement*	*Adults and Children 4 or more Years of Age*	*Infants*	*Children Under 4 Years of Age*	*Pregnant or Lactating Women*
Vitamin A	International Units†	5000 (1000 μg)	1500	2500	8000
Vitamin D	International Units†	400 (10 μg)	400	400	400
Vitamin E	International Units†	30 (10 μg)	5	10	30
Vitamin C	Milligrams	60	35	40	60
Folic acid	Micrograms	400	0.1	0.2	0.8
Thiamin	Milligrams	1.5	0.5	0.7	1.7
Riboflavin	Milligrams	1.7	0.6	0.8	2.0
Niacin	Milligrams	20	8	9	20
Vitamin B_6	Milligrams	2.0	0.4	0.7	2.5
Vitamin B_{12}	Micrograms	6.0	2	3	8
Biotin	Micrograms	300	0.05	0.15	0.30
Pantothenic acid	Milligrams	10	3	5	10
Calcium	Milligrams	1000	0.6	0.8	1.3
Phosphorous	Milligrams	1000	0.5	0.8	1.3
Iodine	Micrograms	150	45	70	150
Iron	Milligrams	18	15	10	18
Magnesium	Milligrams	400	70	200	450
Copper	Milligrams	2.0	0.6	1.0	2.0
Zinc	Milligrams	15	5	8	15
Vitamin K	Micrograms	80	—‡	—‡	—‡
Chromium	Micrograms	120	—	—	—
Selenium	Micrograms	70	—	—	—
Molybdenum	Micrograms	75	—	—	—
Manganese	Milligrams	2	—	—	—
Chloride	Milligrams	3400	—	—	—

*Based on National Academy of Sciences' 1968 Recommended Dietary Allowances.

†The RDIs for fat-soluble vitamins are expressed in International Units (IU). Values that are approximately equivalent in micrograms are given in parentheses.

‡No values yet established for vitamin K, chromium, selenium, molybdenum, manganese, or chloride for this population.

Source: USDA Food Labeling Guide. Available online at http://www.cfsan.fda.gov/~dms/2lg-xf.htm

Daily Reference Values (DRVs) used to Establish Daily Values*

Nutrient	Daily Reference Value	Amount in 2000-Kcalorie Diet	Amount in 2500-Kcalorie Diet
Total fat	<30% of kcalories	65 g	80 g
Saturated fat	<10% of kcalories	20 g	25 g
Total carbohydrate	60% of kcalories	300 g	375 g
Dietary fiber	11.5 g/1000 kcalories	25 g	30 g
Protein	10% of kcalories	50 g	63 g
Cholesterol	<300 mg	<300 mg	<300 mg
Sodium	<2400 mg	<2400 mg	<2400 mg
Potassium	3500 mg	3500 mg	3500 mg

*The Nutrition Facts portion of food labels lists Daily Values (DV). These are based on two sets of preference values: Daily Reference Values (DRVs) and Reference Daily Intakes (RDIs). DRVs are established for adults and children four or more years of age. DRVs are provided for total fat, saturated fat, cholesterol, total carbohydrate, dietary fiber, sodium, potassium, and protein. RDIs are provided for vitamins and minerals and for protein for children less than four years of age and for pregnant and lactating women.

Appendix C

Dietary Guidelines for Americans, 2015–2020

The Guidelines[a]

1. **Follow a healthy eating pattern across the lifespan.**
   All food and beverage choices matter. Choose a healthy eating pattern at an appropriate calorie level to help achieve and maintain a healthy body weight, support nutrient adequacy, and reduce the risk of chronic disease.
2. **Focus on variety, nutrient density, and amount.**
   To meet nutrient needs within calorie limits, choose a variety of nutrient-dense foods across and within all food groups in recommended amounts.
3. **Limit calories from added sugars and saturated fats and reduce sodium intake.**
   Consume an eating pattern low in added sugars, saturated fats, and sodium. Cut back on foods and beverages higher in these components to amounts that fit within healthy eating patterns.
4. **Shift to healthier food and beverage choices.**
   Choose nutrient-dense foods and beverages across and within all food groups in place of less healthy choices. Consider cultural and personal preferences to make these shifts easier to accomplish and maintain.
5. **Support healthy eating patterns for all.**
   Everyone has a role in helping to create and support healthy eating patterns in multiple settings nationwide, from home to school to work to communities.

[a]U.S. Department of Health and Human Services and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.

Key Recommendations

The *Dietary Guidelines'* Key Recommendations for healthy eating patterns should be applied in their entirety, given the interconnected relationship that each dietary component can have with others.

Consume a healthy eating pattern that accounts for all foods and beverages within an appropriate calorie level.

A healthy eating pattern includes

- A variety of vegetables from all of the subgroups—dark green, red and orange, legumes (beans and peas), starchy, and other
- Fruits, especially whole fruits
- Grains, at least half of which are whole grains
- Fat-free or low-fat dairy, including milk, yogurt, cheese, and/or fortified soy beverages
- A variety of protein foods, including seafood, lean meats and poultry, eggs, legumes (beans and peas), and nuts, seeds, and soy products
- Oils

A healthy eating pattern limits

- Saturated fats and *trans* fats, added sugars, and sodium

Key Recommendations that are quantitative are provided for several components of the diet that should be limited. These components are of particular public health concern in the United States, and the specified limits can help individuals achieve healthy eating patterns within calorie limits:

- Consume less than 10 percent of calories per day from added sugars
- Consume less than 10 percent of calories per day from saturated fats
- Consume less than 2,300 milligrams (mg) per day of sodium
- If alcohol is consumed, it should be consumed in moderation—up to one drink per day for women and up to two drinks per day for men—and only by adults of legal drinking age.

In tandem with the recommendations above, Americans of all ages—children, adolescents, adults, and older adults—should meet the *Physical Activity Guidelines for Americans* to help promote health and reduce the risk of chronic disease. Americans should aim to achieve and maintain a healthy body weight. The relationship between diet and physical activity contributes to calorie balance and managing body weight. As such, the *Dietary Guidelines* includes a Key Recommendation to

- Meet the *Physical Activity Guidelines for Americans*[a]

[a]U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans.* Washington (DC): U.S. Department of Health and Human Services; 2008. ODPHP Publication No. U0036. Available at: http://www.health.gov/paguidelines. Accessed January 15, 2016.

Appendix D

Energy Expenditure for Various Activities

Energy Expenditure for Various Activities

	Kcalories per Hour (by body weight)				
Type of Activity	**100 lb**	**120 lb**	**150 lb**	**180 lb**	**200 lb**
Aerobics (heavy)	363	435	544	653	726
Aerobics (medium)	227	272	340	408	454
Aerobics (light)	136	163	204	245	272
Archery	159	190	238	286	317
Backpacking	408	490	612	735	816
Badminton (doubles)	181	218	272	327	363
Badminton (singles)	231	278	347	416	463
Basketball (nonvigorous)	431	517	646	776	862
Basketball (vigorous)	499	599	748	898	998
Bicycling (6 mph)	159	190	238	286	317
Bicycling (10 mph)	249	299	374	449	499
Bicycling (11 mph)	295	354	442	531	590
Bicycling (12 mph)	340	408	510	612	680
Bicycling (13 mph)	385	463	578	694	771
Billiards	91	109	136	163	181
Bowling	177	212	265	318	354
Boxing—competition	603	724	905	1086	1206
Boxing—sparring	376	452	565	678	753
Calisthenics (heavy)	363	435	544	653	726
Calisthenics (light)	181	218	272	327	363
Canoeing (2.5 mph)	150	180	224	269	299
Canoeing (5 mph)	340	408	510	612	680
Carpentry	227	272	340	408	454
Climbing (mountain)	454	544	680	816	907
Disco dancing	272	327	408	490	544
Ditch digging (hand)	263	316	395	473	526
Fencing	340	408	510	612	680
Fishing (bank/boat)	159	190	238	286	317
Fishing (in waders)	249	299	374	449	499
Football (touch)	340	408	510	612	680
Gardening	145	174	218	261	290
Golf (carry clubs)	227	272	340	408	454
Golf (pull cart)	163	196	245	294	327
Golf (ride in cart)	113	136	170	204	227
Handball (vigorous)	454	544	680	816	907
Hiking (X-country)	249	299	374	449	499
Hiking (mountain)	340	408	510	612	680
Horseback trotting	231	278	347	416	463

(continued)

Energy Expenditure for Various Activities *(continued)*

	Kcalories per Hour (by body weight)				
Type of Activity	**100 lb**	**120 lb**	**150 lb**	**180 lb**	**200 lb**
Housework	181	218	272	327	363
Hunting (carry load)	272	327	408	490	544
Ice hockey (vigorous)	454	544	680	816	907
Ice skating (10 mph)	263	316	395	473	526
Jazzercise (heavy)	363	435	544	653	726
Jazzercise (medium)	227	272	340	408	454
Jazzercise (light)	136	163	204	245	272
Jog (9 min/mile)	499	599	748	898	998
Jog (10 min/mile)	454	544	680	816	907
Jog (12 min/mile)	385	463	578	694	771
Jog (13 min/mile)	317	381	476	571	635
Jog (14 min/mile)	272	327	408	490	544
Jog (15 min/mile)	227	272	340	408	454
Jog (17 min/mile)	181	218	272	327	363
Lawn mowing (hand)	295	354	442	531	590
Lawn mowing (power)	163	196	245	294	327
Musical instrument playing	113	136	170	204	227
Racquetball (social)	385	463	578	694	771
Racquetball (vigorous)	454	544	680	816	907
Roller skating	231	278	347	416	463
Rowboating (2.5 mph)	200	239	299	359	399
Rowing (11 mph)	590	707	884	1061	1179
Run (5 min/mile)	816	980	1224	1469	1633
Run (6 min/mile)	703	844	1054	1265	1406
Run (7 min/mile)	612	735	918	1102	1224
Run (8 min/mile)	544	653	816	980	1088
Sailing	159	190	238	286	317
Shuffleboard/skeet	136	163	204	245	272
Skiing (X-country)	454	544	680	816	907
Skiing (downhill)	363	435	544	653	726
Square dancing	272	327	407	490	544
Swimming (competitive)	680	816	1020	1224	1361
Swimming (fast)	426	512	639	767	853
Swimming (slow)	349	419	524	629	698
Table tennis	236	283	354	424	472
Tennis (doubles)	227	272	340	408	454
Tennis (singles)	295	354	442	531	590
Tennis (vigorous)	385	463	578	694	771
Volleyball	231	278	347	416	463
Walking (20 min/mile)	159	190	238	286	317
Walking (26 min/mile)	136	163	204	245	272
Water skiing	317	381	476	571	635
Weight lifting (heavy)	408	490	612	735	816
Weight lifting (light)	181	218	272	327	363
Wood chopping (sawing)	295	354	442	531	590

Source: Data reprinted with permission from N-Squared Computing. First Databank Division of the Hearst Corporation.

Glossary

A

absorption The process of taking substances into the interior of the body.

Acceptable Daily Intake (ADI) The amount of a substance in food or drinking water that can be safely consumed daily over a lifetime without adverse effects.

Acceptable Macronutrient Distribution Ranges (AMDRs) Ranges of intake for energy-yielding nutrients, expressed as a percentage of total energy intake, that are associated with reduced risk of chronic disease while providing adequate intakes of essential nutrients.

accidental contaminant A substance not regulated by the FDA that unexpectedly enters the food supply.

acesulfame K (acesulfame potassium) An alternative sweetener that contains no energy and is 200 times as sweet as sugar.

acetylcholine A neurotransmitter that functions in the brain and other parts of the nervous system.

acetyl-CoA A metabolic intermediate formed during the breakdown of glucose, fatty acids, and amino acids. It is a two-carbon compound attached to a molecule of CoA.

acid A substance that releases hydrogen ions (H^+) in solution.

acrodermatitis enteropathica An inherited defect in zinc absorption and metabolism that leads to severe zinc deficiency.

active transport The transport of substances across a cell membrane with the aid of a carrier molecule and the expenditure of energy. This may occur against a concentration gradient.

adaptive thermogenesis The change in energy expenditure induced by factors such as changes in ambient temperature and food intake.

added sugars Sugars and syrups that have been added to foods during processing or preparation.

adenosine triphosphate See ATP.

Adequate Intakes (AIs) Intakes that should be used as a goal when no RDA exists. These values are an approximation of the average nutrient intake that appears to sustain a desired indicator of health.

adipocyte A fat-storing cell.

adipose tissue Tissue found under the skin and around body organs that is composed of fat-storing cells.

adjustable gastric banding A surgical procedure to treat obesity in which an adjustable band is placed around the upper portion of the stomach in order to limit the volume that the stomach can hold and the rate of stomach emptying.

adolescent growth spurt An 18- to 24-month period of peak growth velocity that begins at about ages 10 to 13 in girls and ages 12 to 15 in boys.

adrenaline See epinephrine.

aerobic capacity or **VO_2 max** The maximum amount of oxygen that can be consumed by the tissues during exercise. This is also called maximal oxygen consumption.

aerobic exercise Endurance exercise such as jogging, swimming, or cycling that increases heart rate and requires oxygen in metabolism.

aerobic metabolism Metabolism in the presence of oxygen, which can completely break down glucose to yield carbon dioxide, water, and as many as 38 ATP molecules.

aflatoxin An extremely potent carcinogen that is produced by a mold that grows on peanuts, corn, and grains.

age-related bone loss The bone loss that occurs in both the cortical and trabecular bone of men and women as they advance in age.

aging The process of becoming older. It is genetically determined and modulated by environmental and lifestyle factors.

AIDS (acquired immune deficiency syndrome) The syndrome caused by HIV infection that causes the immune system to fail, resulting in frequent recurrent infections.

alcohol dehydrogenase (ADH) An enzyme found primarily in the liver and stomach that helps break down alcohol into acetaldehyde, which is then converted to acetyl-CoA.

alcoholic hepatitis Inflammation of the liver caused by alcohol consumption.

alcoholism see alcohol use disorder.

alcohol poisoning When the quantity of alcohol consumed exceeds an individual's tolerance for alcohol and impairs mental and physical abilities.

alcohol use disorder or **alcoholism** A chronic disorder characterized by dependence on alcohol and development of withdrawal symptoms when alcohol intake is reduced.

aldosterone A hormone that increases sodium reabsorption by the kidney and therefore enhances water retention.

allergen A substance that causes an allergic reaction.

allergy An adverse reaction involving the immune system that results from exposure to a specific allergen.

alimentary canal See gastrointestinal tract.

alpha-carotene (α-carotene) A carotenoid, some of which can be converted into vitamin A, that is found in leafy green vegetables, carrots, and squash.

alpha-linolenic acid (α-linolenic acid) An 18-carbon omega-3 polyunsaturated fatty acid known to be essential in humans.

alpha-tocopherol (α-tocopherol) The form of tocopherol that provides vitamin E activity in humans.

alveoli (singular, alveolus) Milk-producing glands in the breast.

Alzheimer's disease A disease that causes the relentless and irreversible loss of mental function.

amenorrhea Delayed onset of menstruation or absence of three or more consecutive menstrual cycles.

amino acid pool All of the amino acids in body tissues and fluids that are available for use by the body.

amino acids The building blocks of proteins. Each contains a central carbon atom bound to a hydrogen atom, an amino group, an acid group, and a side chain.

amino acid score See chemical score.

amylase A plant starch that is composed of long unbranched chains of glucose molecules.

amylopectin A plant starch that is composed of long, branched chains of glucose molecules.

anabolic pathways Energy-requiring biochemical reactions in which simpler molecules are combined to form more complex substances.

anabolic steroids Synthetic fat-soluble hormones that mimic testosterone and are used by some athletes to increase muscle strength and mass.

anabolism The metabolic processes that use energy to combine simpler molecules to form more complex substances.

anaerobic metabolism or **anaerobic glycolysis** Metabolism in the absence of oxygen. Each molecule of glucose generates two molecules of ATP. Glucose is metabolized in this way when the blood cannot deliver oxygen to the tissues quickly enough to support aerobic metabolism.

anaphylaxis An immediate and severe allergic reaction to a substance (e.g., food or drugs). Symptoms include breathing difficulty, loss of consciousness, and a drop in blood pressure and can be fatal.

androstenedione A compound (known as andro) that can be converted into testosterone and estrogen inside the body. It is a controlled substance used by athletes to increase muscle mass and strength.

anemia A condition in which the oxygen-carrying capacity of the blood is decreased by a reduced number of red blood cells or a reduced amount of hemoglobin in the cells.

anencephaly A birth defect due to failure of the neural tube to close; it results in the absence of a major portion of the brain, skull, and scalp.

angiotensin II A compound that causes blood vessel walls to constrict and stimulates the release of the hormone aldosterone.

anisakiasis A disease caused by infection of the gastrointestinal tract with the *Anisakis simplex* roundworm, which can contaminate raw fish.

anorexia athletica A type of eating disorder that is characterized by engaging in compulsive exercise to eliminate excess calories.

anorexia nervosa An eating disorder characterized by self-starvation, a distorted body image, and below-normal body weight.

anthropometric measurements External measurements of the body, such as height, weight, limb circumference, and skinfold thickness.

antibiotic A substance that inhibits the growth of or destroys microorganisms; used to treat or prevent infection.

antibiotic resistance When bacteria or other microbes that cause disease evolve into forms that can no longer be killed by a particular antibiotic.

antibody A protein produced by the body's immune system that recognizes a foreign substance in the body and helps destroy it.

anticaking agent A substance added to dry food products to prevent clumping.

anticoagulant A substance that delays or prevents blood clotting.

antidiuretic hormone (ADH) A hormone secreted by the pituitary gland that increases the amount of water reabsorbed by the kidney and therefore retained in the body.

antigen A foreign substance (almost always a protein) that, when introduced into the body, stimulates an immune response.

antioxidant A substance that significantly decreases the adverse effects of free radicals and other reactive species on normal physiological function.

antithiamin factor A substance in food that destroys the vitamin thiamin. Some are enzymes and are destroyed by cooking; others are not inactivated by cooking.

anus The outlet of the rectum through which feces are expelled.

apolipoprotein B A protein embedded in the outer shell of low-density lipoprotein (LDL) particles that binds to LDL receptor proteins on body cells.

appetite A desire to consume specific foods that is independent of hunger.

aquaculture The controlled cultivation and harvest of aquatic plants or animals.

arachidonic acid A 20-carbon omega-6 polyunsaturated fatty acid that can be synthesized from linoleic acid.

ariboflavinosis A condition resulting from a deficiency of riboflavin characterized by inflammation of the eyes, lips, mouth, and tongue.

arteriole A small artery that carries blood to capillaries.

artery A vessel that carries blood away from the heart.

arthritis A disease characterized by inflammation of the joints, joint pain, and sometimes changes in joint structure.

ascorbic acid or **ascorbate** The chemical term for vitamin C.

aseptic processing A method that places sterilized food in a sterilized package using a sterile process.

aspartame An alternative sweetener that is 200 times as sweet as sugar and is composed of the amino acids phenylalanine and aspartic acid.

atherosclerosis A type of cardiovascular disease that involves the buildup of fatty material in the artery walls.

atherosclerotic plaque The cholesterol-rich material that is deposited in the arteries of individuals with atherosclerosis. It consists of cholesterol, smooth muscle cells, fibrous tissue, and eventually calcium.

atom The smallest unit of an element that still retains the properties of that element.

ATP (adenosine triphosphate) The high-energy molecule used by the body to perform energy-requiring activities.

atrophic gastritis An inflammation of the stomach lining that results in reduced secretion of stomach acid and bacterial overgrowth.

atrophy Wasting or decrease in the size of a muscle or other tissue caused by lack of use.

attention deficit/hyperactivity disorder (ADHD) A condition characterized by a short attention span, acting without thinking, and a high level of activity, excitability, and distractibility.

autoimmune disease A disease that results from immune reactions that destroy normal body cells.

avidin A protein found in raw egg whites that binds biotin, preventing its absorption.

B

bacteria (singular, bacterium) Tiny single-celled organisms found throughout the environment. Most are harmless or beneficial, but a few types can cause disease in humans.

balance study A study that compares the total amount of a nutrient that enters the body with the total amount that leaves the body.

bariatric surgery Surgical procedure performed on the stomach and/or intestines to induce weight loss.

basal energy expenditure (BEE) The energy expended to maintain an awake resting body that is not digesting food.

basal metabolic rate (BMR) The rate of energy expenditure under resting conditions. BMR measurements are performed in a warm room in the morning before the subject rises and at least 12 hours after the last food or activity.

basal metabolism The energy expended to maintain an awake resting body that is not digesting food.

base A substance that accepts hydrogen ions in solution.

behavior modification A process used to gradually and permanently change habitual behaviors.

beriberi A thiamin deficiency disease that may manifest in one of two forms: dry beriberi, which causes weakness and nerve degeneration, or wet beriberi, which damages the heart.

beta-carotene (*β*-carotene) A carotenoid that has more provitamin A activity than other carotenoids. It also acts as an antioxidant.

beta-cryptoxanthin (*β*-cryptoxanthin) A carotenoid found in corn, green peppers, and lemons that can provide some vitamin A activity.

beta-oxidation (β-oxidation) The first step in the production of ATP from fatty acids. This pathway breaks the carbon chain of fatty acids into two-carbon units that form acetyl-CoA and release high-energy electrons that are passed to the electron transport chain.

bile A digestive fluid made in the liver and stored in the gallbladder that is released into the small intestine, where it aids in fat digestion and absorption.

bile acids Emulsifiers present in bile that are synthesized by the liver from cholesterol.

binge drinking A pattern of drinking that brings a person's blood alcohol concentration to 80 mg/100 mL or above.

binge eating The rapid consumption of a large amount of food in a discrete period of time associated with a feeling that eating is out of control.

binge-eating disorder An eating disorder characterized by recurrent episodes of binge eating in the absence of purging behavior.

bioaccumulation The process by which compounds accumulate or build up in an organism faster than they can be broken down or excreted.

bioavailability A general term describing how well a nutrient can be absorbed and used by the body.

bioelectric impedance analysis A technique for estimating body composition that measures body fat by directing a low-energy electric current through the body and calculating resistance to flow.

biological value A measure of protein quality determined by comparing the amount of nitrogen retained in the body with the amount absorbed from the diet.

biotechnology The process of manipulating life forms via genetic engineering in order to provide desirable products for human use.

biotin A B vitamin needed in energy metabolism.

blackout drinking Amnesia following a period of excess alcohol consumption.

blood pressure The amount of force exerted by the blood against the artery walls.

body image The way a person perceives and imagines his or her body.

body mass index (BMI) A measure of body weight in relation to height that is used to compare body size with a standard.

bomb calorimeter An instrument used to determine the energy content of food. It measures the heat energy released when a dried food is combusted.

bone remodeling The process whereby bone is continuously broken down and re-formed to allow for growth and maintenance.

botulism A severe food-borne intoxication that results from consuming the toxin produced by the bacterium *Colostridium botulinum*.

bovine somatotropin (bST) A hormone naturally produced by cows that stimulates the production of milk. A synthetic version of this hormone is now being produced by genetic engineering.

bovine spongiform encephalopathy (BSE) A fatal neurological disease, also known as mad cow disease, that affects cattle and may be transmitted to humans by consuming beef by-products.

bran The protective outer layers of whole grains. It is a concentrated source of dietary fiber.

brown adipose tissue A type of fat tissue that has a greater number of mitochondria than the more common white adipose tissue. It can waste energy as heat.

brush border Refers to the microvilli surface of the intestinal mucosa, which contains some digestive enzymes.

buffer A substance that reacts with an acid or base by picking up or releasing hydrogen ions to prevent changes in pH.

bulimia nervosa An eating disorder characterized by the consumption of large amounts of food at one time (binge eating), followed by purging behaviors such as vomiting or the use of laxatives to eliminate calories from the body.

C

calcitonin A hormone secreted by the thyroid gland that reduces blood calcium levels.

calorie The amount of heat required to raise the temperature of 1 g of water 1 degree Celsius; equal to 4.18 joules. Typically used to refer to the number of kilocalories in food or expended by the body.

calorimetry A technique for measuring energy expenditure.

Campylobactor jejuni A bacterium common in raw milk and undercooked meat that causes food-borne illness.

capillary A small, thin-walled blood vessel where the exchange of gases and nutrients between blood and body cells occurs.

carbohydrate A compound containing carbon, hydrogen, and oxygen in the same proportions as in water; includes sugars, starches, and most fibers.

carbohydrate loading See Glycogen supercompensation.

carcinogen A substance that causes cancer.

cardiorespiratory endurance The efficiency with which the body delivers to cells the oxygen and nutrients needed for muscular activity and transports waste products from cells.

cardiovascular disease Any disease affecting the heart and blood vessels.

caries see dental caries.

carnitine A molecule synthesized in the body that is needed to transport fatty acids and some amino acids into the mitochondria for metabolism.

carotenoids Natural pigments synthesized by plants and many microorganisms. They give yellow, orange, and red fruits and vegetables their color.

carpal tunnel syndrome Numbness, tingling, weakness, and pain in the hand caused by pressure on the nerves.

case-control study A type of observational study that compares individuals with a particular condition under study with individuals of the same age, gender, and background who do not have the condition.

casein The predominant protein in cow's milk.

cash crop A crop that is grown to be sold for monetary return, rather than to feed the local population.

catabolic pathways The biochemical reactions by which substances are broken down into simpler molecules releasing energy.

catabolism The processes by which substances are broken down into simpler molecules releasing energy.

catalase An iron-containing enzyme that destroys peroxides.

cataract A disease of the eye that results in cloudy spots on the lens (and sometimes the cornea) that obscure vision.

celiac disease A disorder that causes damage to the intestines when the protein gluten is eaten.

cell The basic structural and functional unit of living things.

cell differentiation Structural and functional changes that cause cells to mature into specialized cells.

cell membrane The membrane that surrounds the cell contents.

cellular respiration The reactions that break down glucose, fatty acids, and amino acids in the presence of oxygen to produce carbon dioxide, water, and energy in the form of ATP.

cellulose An insoluble fiber that is the most prevalent structural material of plant cell walls.

cephalic response The stimulation of gastric secretion by the sight, smell, and sound of food preparation.

certified food color A food color that has been tested and certified for safety, quality, consistency, and strength of color.

ceruloplasmin The major copper-carrying protein in the blood.

cesarean section The surgical removal of the fetus from the uterus.

chemical bond Force that holds atoms together.

chemical or **amino acid score** A measure of protein quality determined by comparing the essential amino acid content of the protein in a food with that in a reference protein. The lowest amino acid ratio calculated is the chemical score.

Chinese restaurant syndrome See MSG symptom complex.

Choice (Exchange) Lists A system of grouping foods based on their energy and macronutrient content.

cholecalciferol The chemical name for vitamin D_3. It can be formed in the skin of animals by the action of sunlight on 7-dehydrocholesterol.

cholecystokinin (CCK) A hormone released by the duodenum that stimulates the release of pancreatic juice rich in digestive enzymes and causes the gallbladder to contract and release bile into the duodenum.

cholesterol A lipid that consists of multiple chemical rings and is made only by animal cells.

cholic acid A bile acid.

choline A compound needed for the synthesis of the phospholipid phosphatidylcholine (lecithin) and the neurotransmitter acetylcholine. It is important for a number of biochemical reactions, and there is evidence that it is essential in the diet during certain stages of life.

chromium picolinate A form of chromium sold as a supplement promoted to change body composition. Chromium is involved in insulin action, and supplements claim to increase lean body mass, decrease body fat, and delay fatigue. There is little evidence of its effectiveness as an ergogenic aid.

chylomicron A lipoprotein that transports lipid from the mucosal cells of the small intestine and delivers triglycerides to other body cells.

chyme A mixture of partially digested food and stomach secretions.

chymotrypsin A protein-digesting enzyme produced in an inactive form in the pancreas and activated in the small intestine, where it aids digestion.

circulatory system The organ system consisting of the heart, blood, and blood vessels, that transports material to and from cells.

cirrhosis Chronic liver disease characterized by the loss of functioning liver cells and the accumulation of fibrous connective tissue.

citric acid cycle Also known as the Krebs cycle or the tricarboxylic acid cycle, this is the stage of cellular respiration in which two carbons from acetyl-CoA are oxidized, producing two molecules of carbon dioxide.

clinical trial see human intervention study.

clone A copy that is identical to the original.

Clostridium botulinum A bacterium that produces a deadly toxin and grows in a low-acid, low-oxygen environment, such as inside certain canned goods.

Clostridium perfringens A bacterium found in meat and poultry that can cause food-borne illness.

coagulation The process of blood clotting.

cobalamin The chemical term for a cobalt-containing compound commonly known as vitamin B_{12}.

coenzyme A small nonprotein organic molecule that acts as a carrier of electrons or atoms in metabolic reactions and is necessary for the proper functioning of many enzymes.

coenzyme Q or **ubiquinone** A coenzyme that transfers electrons from one molecule to another in the electron transport chain of cellular respiration.

cofactor An inorganic ion or coenzyme required for enzyme activity.

colic Episodes of inconsolable crying in an otherwise healthy infant between the ages of 2 weeks and 4 months. The cause is unknown.

collagen The major protein in connective tissue and the most abundant protein in the body.

colon The largest portion of the large intestine.

colostrum The first milk, which is secreted in late pregnancy and up to a week after birth. It is rich in protein and immune factors.

complete dietary protein Protein that provides essential amino acids in the proportions needed to support protein synthesis.

complex carbohydrates Carbohydrates composed of sugar molecules linked together in straight or branching chains. They include oligosaccharides, glycogen, starches, and fibers.

compression of morbidity The postponement of the onset of chronic disease so that disability occupies a smaller and smaller proportion of the life span.

conception The union of sperm and egg (ovum) that results in pregnancy.

conditionally essential amino acid An amino acid that is essential in the diet only under certain conditions or at certain times of life.

connective tissue One of the four human tissue types; includes cartilage, bone, blood, adipose tissue, and the coverings of some organs.

constipation Infrequent or difficult defecation.

control group In a scientific experiment, the group of participants used as a basis of comparison. They are similar to the participants in the experimental group but do not receive the treatment being tested.

coronary heart disease A disease of the heart and blood vessels that supply blood to the heart.

correlation Two or more factors occurring together.

cortical or **compact bone** Dense, compact bone that makes up the sturdy outer surface layer of bones.

creatine A compound that can be converted into creatine phosphate, which replenishes muscle ATP during short bursts of activity. Creatine is a dietary supplement used by athletes to increase muscle mass and delay fatigue during short intense exercise.

creatine phosphate or **phosphocreatine** A compound found in muscle that can be broken down quickly to generate ATP.

cretinism A condition resulting from poor maternal iodine intake during pregnancy that causes stunted growth and impaired cognitive development in offspring.

critical control points Possible points in the food production, manufacturing, and transportation processes at which controls can be applied and contamination prevented or eliminated.

critical periods Times in growth and development when an organism is more susceptible to harm from poor nutrition or other environmental factors.

cross-contamination The transfer of contaminants from one food or object to another.

cross-sectional data Information obtained by a single broad sampling of many different individuals in a population.

cruciferous A group of vegetables (also called crucifers) named for the cross shape of their four-petal flowers. They include broccoli, Brussels sprouts, cabbage, cauliflower, kale, kohlrabi, mustard greens, rutabagas, and turnips. Their consumption is linked with lower rates of cancer.

cycle of undernutrition A cycle in which undernutrition is perpetuated by an inability to meet nutrient needs at all life stages.

cysteine A conditionally essential sulfur-containing amino acid; when methionine is available in sufficient quantities, cysteine is not essential in the diet.

cytosol The liquid found within cells.

D

Daily Reference Values (DRVs) Reference values established for protein and seven nutrients for which no original RDAs were established. The values are based on dietary recommendations for reducing the risk of chronic disease.

Daily Value A nutrient reference value used on food labels to help consumers see how foods fit into their overall diets.

DASH diet A dietary pattern that is plentiful in fruits and vegetables and low-fat dairy products and therefore high in potassium, magnesium, calcium, and fiber, and low in saturated fat and cholesterol.

deamination The removal of the amino group from an amino acid.

decarboxylation The removal of a carboxyl group (COOH) from a chemical compound.

dehydration A condition that results when not enough water is present to meet the body's needs.

dehydration reaction Chemical reaction that joins two molecules together. Hydrogen and oxygen are lost from the two molecules to form water.

Delaney Clause A clause added to the 1958 Food Additives Amendment of the Pure Food and Drug Act that prohibits the intentional addition to foods of any compound that has been shown to induce cancer in animals or humans at any dose.

dementia A deterioration of mental state resulting in impaired memory, thinking, and/or judgment.

denaturation The alteration of a protein's three-dimensional structure.

dental caries The decay and deterioration of teeth caused by acid produced when bacteria on the teeth metabolize carbohydrate.

deoxyribose The 5-carbon sugar that is part of DNA.

depletion-repletion study A study that feeds a diet devoid of a nutrient until signs of deficiency appear and then adds the nutrient back to the diet to a level at which symptoms disappear.

dermatitis An inflammation of the skin.

DHA See Docosahexaenoic acid.

DHEA (dehydroepiandosterone) A precursor of the sex hormones testosterone, estrogen, and progesterone; a banned substance used to slow aging and to increase muscle mass.

diabetes mellitus A disease caused by insufficient insulin production and/or decreased sensitivity of cells to insulin. It results in elevated blood glucose levels.

diabulimia The manipulation of insulin treatment by diabetic patients in order to lose weight.

diacylglycerol see diglyceride

diarrhea An intestinal disorder characterized by frequent or watery stools.

dicumarol An anticoagulant first isolated from moldy clover hay.

dietary antioxidant A substance in food that significantly decreases the adverse effects of reactive species on normal physiological function in humans.

dietary folate equivalents (DFEs) The unit used to express folate recommendations. One DFE is equivalent to 1 μg of folate naturally occurring in food, 0.6 μg of synthetic folic acid from fortified food or supplements consumed with food, or 0.5 μg of synthetic folic acid consumed on an empty stomach.

Dietary Guidelines for Americans A set of nutrition recommendations designed to promote population-wide dietary changes to reduce the incidence of nutrition-related chronic disease.

Dietary Reference Intakes (DRIs) A set of reference values for the intake of energy, nutrients, and food components that can be used for planning and assessing the diets of healthy people in the United States and Canada.

dietary supplement A product intended for ingestion in the diet that contains one or more of the following: vitamins, minerals, plant-derived substances, amino acids, and concentrates or extracts.

diet history Information about dietary habits and patterns.

diet-induced thermogenesis See Thermic effect of food (TEF).

diffusion The movement of molecules from an area of higher concentration to an area of lower concentration without the expenditure of energy.

digestion The process of breaking food into components small enough to be absorbed into the body.

digestive system The organ system responsible for the ingestion of food, the digestion and absorption of nutrients and the elimination of food residues; includes the gastrointestinal tract as well as a number of accessory organs.

digestive tract See Gastrointestinal tract.

diglyceride or **diacylglycerol** A molecule of glycerol with two fatty acids attached.

dipeptide Two amino acids linked by a peptide bond.

direct calorimetry A method of determining energy use that measures the amount of heat produced.

direct food additive A substance that is intentionally added to food. Direct food additives are regulated by the FDA.

disaccharide A carbohydrate made up of two sugar units.

dissociate To separate two charged ions.

diuretic A drug that promotes fluid excretion.

diverticula Sacs or pouches that protrude from the wall of the large intestine.

diverticulitis A condition in which diverticula in the large intestine become inflamed.

diverticulosis A condition in which pouches called **diverticula** protrude from the wall of the large intestine.

DNA (deoxyribonucleic acid) The genetic material found in the nucleus that codes for the synthesis of proteins.

docosahexaenoic acid (DHA) A 22-carbon omega-3 polyunsaturated fatty acid found in fish that may be needed in the diet of newborns. It can be synthesized from α-linolenic acid.

double-blind study An experiment in which neither the study participants nor the researchers know which participants are in a control or an experimental group.

doubly labeled water technique A method for measuring energy expenditure based on measuring the disappearance of isotopes of hydrogen and oxygen in body fluids after consumption of a defined amount of water labeled with both isotopes.

Down syndrome A disorder caused by extra genetic material that results in cognitive disabilities, distinctive facial characteristics, and other abnormalities.

duodenum The upper segment of the small intestine that connects to the stomach.

E

eating disorder A persistent disturbance in eating behavior or other behaviors intended to control weight that affects physical health and psychosocial functioning.

edema Swelling due to the buildup of extracellular fluid in the tissues.

eicosanoids Regulatory molecules, including prostaglandins and related compounds, that can be synthesized from omega-3 and omega-6 fatty acids.

eicosapentaenoic acid (EPA) A 20-carbon omega-3 polyunsaturated fatty acid found in fish that can be synthesized from α-linolenic acid but may be essential in humans under some conditions.

electrolytes Positively and negatively charged ions that conduct an electrical current in solution. Commonly refers to sodium, potassium, and chloride.

electron High-energy particle carrying a negative charge that orbits the nucleus of an atom.

electron transport chain The final stage of cellular respiration in which electrons are passed down a chain of molecules to oxygen to form water and produce ATP.

element A substance that cannot be broken down into products with different properties.

elimination diet and **food challenge** A regimen that eliminates potential allergy-causing foods from an individual's diet and then systematically adds them back to identify any foods that cause an allergic reaction.

embryo The developing human from two to eight weeks after fertilization. All organ systems are formed during this time.

empty calories Calories from solid fats and/or added sugars, which add calories to the food but few nutrients.

emulsifier A substance that allows water and fat to mix by breaking large fat globules into smaller ones.

endocrine system Organ system composed of cells, tissues, and organs that secrete hormones to help control body functions.

endoplasmic reticulum A cellular organelle involved in the synthesis of proteins and lipids and composed of a system of membranous tubules, channels, and sacs in the cytosol; rough endoplasmic reticulum has ribosomes on its outside surface.

endorphins Compounds that cause a natural euphoria and reduce the perception of pain under certain stressful conditions.

endosperm The largest portion of a kernel of grain. It is primarily starch and serves as a food supply for the sprouting seed.

energy The capacity to do work.

energy balance The amount of energy consumed in the diet compared with the amount expended by the body over a given period.

energy-yielding nutrient A nutrient that can be metabolized to provide energy in the body.

enriched Refers to a food that has had nutrients added to restore those lost in processing to a level equal to or higher than originally present.

enriched grains Grain products to which specific amounts of thiamin, riboflavin, niacin, and iron have been added. Since 1998 folic acid has also been added to enriched grains.

enteral or **tube-feeding** A method of feeding by providing a liquid diet directly to the stomach or intestine through a tube placed down the throat or through the wall of the GI tract.

Environmental Protection Agency (EPA) U.S. government agency responsible for determining acceptable levels of environmental contaminants in the food supply and for establishing water quality standards.

enzyme A protein molecule that accelerates the rate of a chemical reaction without itself being changed.

EPA See Environmental Protection Agency

epidemiology The study of the interrelationships between health and disease and other factors in the environment or lifestyle of different populations.

epiglottis A piece of elastic connective tissue at the back of the throat that covers the opening of the passageway to the lungs during swallowing.

epinephrine A hormone secreted by the adrenal gland in response to stress that causes changes, such as an increase in heart rate, in preparation for "fight or flight"; also called adrenaline.

epithelial tissue One of the four human tissue types; includes the cells that cover external body surfaces and line internal cavities and tubes.

ergogenic aid Anything designed to increase work or improve performance.

erythropoietin A protein hormone made by the kidneys that stimulates bone marrow stem cells to produce red blood cells. It can be manufactured using genetic engineering and is injected by endurance athletes as an ergogenic aid known as EPO.

esophagus A portion of the GI tract that extends from the pharynx to the stomach.

essential amino acid or **indispensable amino acid** An amino acid that cannot be synthesized by the human body in sufficient amounts to meet needs and therefore must be included in the diet.

essential fatty acid A fatty acid that must be consumed in the diet because it cannot be made by the body or cannot be made in sufficient quantities to meet needs.

essential fatty acid deficiency A condition characterized by dry scaly skin and poor growth that results when the diet does not supply sufficient amounts of the essential fatty acids.

essential nutrient A nutrient that must be provided in the diet because the body either cannot make it or cannot make it in sufficient quantities to satisfy its needs.

Estimated Average Requirements (EARs) Intakes that meet the estimated nutrient needs of 50% of individuals in a gender and life-stage group.

Estimated Energy Requirements (EERs) The amount of energy recommended by the DRIs to maintain body weight in a healthy person based on age, gender, size, and activity level.

estrogen A steroid hormone secreted by the ovaries and by the placenta that is involved in the maintenance of pregnancy and the maintenance and development of female sex organs and secondary sex characteristics.

ethanol The type of alcohol in alcoholic beverages. It is produced by yeast fermentation of sugar.

excretory system Organ system involved in the elimination of metabolic waste products; includes the lungs, skin, and kidneys.

experimental controls Factors included in an experimental design that limit the number of variables, allowing an investigator to examine the effect of only the parameters of interest.

experimental group In a scientific experiment, the group of participants who undergo the treatment being tested.

extracellular fluid The fluid located outside cells. It includes fluid found in the blood plasma, lymph, gastrointestinal tract, spinal column, eyes, and joints and that found between cells.

F

facilitated diffusion The assisted movement of substances across a cell membrane from an area of higher concentration to an area of lower concentration. No energy is required.

failure to thrive The inability of a child's growth to keep up with normal growth curves.

fallopian tubes or **oviducts** Narrow ducts leading from the ovaries to the uterus.

famine A widespread lack of access to food due to a disaster that causes a collapse in the food production and marketing systems.

fasting hypoglycemia Low blood sugar that is not related to food intake; often caused by an insulin-secreting tumor.

fat A lipid that is solid at room temperature; commonly used to refer to all lipids or specifically to triglycerides.

fat-free mass Body mass composed of all tissue except adipose tissue.

fatigue The inability to continue an activity at an optimal level.

fat-soluble vitamins Vitamins that dissolve in fat.

fatty acid An organic molecule made up of a chain of carbons linked to hydrogen atoms with an acid group at one end.

fatty liver The accumulation of fat in the liver.

fatty streak A cholesterol deposit in the artery wall.
FDA See Food and Drug Administration.
feces Body waste, including unabsorbed food residue, bacteria, mucus, and dead cells, which is excreted from the gastrointestinal tract by passing through the anus.
female athlete triad The combination of energy restriction, menstrual irregularities, and low bone density that occurs in some female athletes, particularly those involved in sports in which low body weight and appearance are important.
fermentation A process in which microorganisms metabolize components of a food and thus change the composition, taste, and storage properties of the food.
ferritin The major iron storage protein.
fertilization The union of sperm and egg (ovum).
fetal alcohol spectrum disorders (FASDs) A continuum of permanent birth defects in a child due to maternal alcohol consumption during pregnancy.
fetal alcohol syndrome (FAS) A characteristic group of physical and mental abnormalities in an infant resulting from maternal alcohol consumption during pregnancy.
fetus The developing human from the ninth week to birth. Growth and refinement of structures occur during this time.
fiber A mixture of indigestible carbohydrates and lignin that is found in plants.
fitness The ability to perform routine physical activity without undue fatigue.
flavin adenine dinucleotide (FAD) and **flavin mononucleotide (FMN)** The active coenzyme forms of riboflavin. The structure of these molecules allows them to pick up and donate hydrogens and electrons in chemical reactions.
flexibility Range of motion.
fluorosis A condition caused by chronic overconsumption of fluoride, characterized by black and brown stains and cracking and pitting of the teeth.
foam cell A cholesterol-filled white blood cell.
folate and **folacin** General terms for the many forms of this B vitamin.
folate monoglutamate A form of the B vitamin folate, also called folic acid, that has one glutamate residue. It is formed during digestion of folate and used in fortified foods and supplements.
folate polyglutamate A form of the B vitamin folate that contains many glutamate residues. All but one must be removed before it can be absorbed from the GI tract.
folic acid The monoglutamate form of folate, which is used in fortified foods and supplements.
food additive A substance that is intentionally added to or can reasonably be expected to become a component of a food during processing.
Food and Drug Administration (FDA) U.S. government agency responsible for the safety and wholesomeness of all food except red meat, poultry, and eggs; also sets standards and enforces regulations for food labeling and for food and color additives.
food-borne illness An illness caused by consumption of contaminated food.
food-borne infection Illness produced by the ingestion of food containing microorganisms that can multiply inside the body and cause injurious effects.
food-borne intoxication Illness caused by consuming a food containing a toxin.
food challenge See Elimination diet and food challenge
Food Code A set of recommendations published by the FDA for the handling and service of food sold in restaurants and other establishments that serve food.
food desert An area that lacks access to affordable fruits, vegetables, whole grains, low-fat milk, and other foods that make up a healthy diet.
food diary A method of assessing dietary intake that involves an individual keeping a written record of all food and drink consumed during a defined period.
food disappearance surveys A survey that estimates the food use of a population by monitoring the amount of food that leaves the marketplace.
food environment The physical, economic, and social factors that affect eating habits and patterns.
food frequency questionnaire A method of assessing dietary intake that gathers information about how often certain categories of food are consumed.
food insecurity A situation in which people lack adequate physical, social, or economic access to sufficient, safe, nutritious food that meets their dietary needs and food preferences to lead an active and healthy life.
food intolerance An adverse reaction to a food that does not involve antibody production by the immune system.
food jag When a child will only eat one food item meal after meal.
food processing The practices used by the food industry to transform raw plant and animal materials, such as grains, produce, meat, and milk, into products for consumers. Nearly all our food has been processed in some way.
food recovery The collection of wholesome food for distribution to the poor and hungry, including collection of crops from farmers' fields that have already been mechanically harvested or from fields where it is not economically profitable to harvest.
food security Access by all people at all times to sufficient food required for a healthy and active life.
Food self-sufficiency The ability of an area to produce enough food to feed its population.
food shortage Insufficient food to feed a population.
fortification A term used to describe the process of adding nutrients to foods.
fortified food Food to which one or more nutrients have been added.
free radical An atom or group of atoms that has at least one unpaired electron and is therefore unstable and highly reactive and can cause cellular damage.
fructose A monosaccharide that is the primary form of carbohydrate found in fruit.
functional foods Foods that provide a potential benefit to health beyond that attributed to the nutrients they contain.

G

galactose A monosaccharide that combines with glucose to form lactose, or milk sugar.
gallbladder An organ of the digestive system that stores bile, which is produced by the liver.
gastric bypass A surgical procedure to treat morbid obesity that both reduces the size of the stomach and bypasses a portion of the small intestine.
gastric juice A collection of secretions including hydrochloric acid and pepsinogen, released by the gastric glands into the stomach.
gastric sleeve surgery A surgical procedure to treat obesity that involves removing a large part of the stomach so the remainder resembles a tube or sleeve in order to limit the volume that the stomach can hold.
gastrin A hormone secreted by the stomach mucosa that stimulates the secretion of gastric juice.
gastroesophageal reflux disease (GERD) A chronic condition in which acidic stomach contents leak back up into the esophagus, causing pain and damaging the esophagus.

gastroesophageal sphincter The muscular valve at the top of the stomach that allows food to enter the stomach from the esophagus and then keeps the food and digestive juice from leaking back up into the esophagus.

gastrointestinal tract A hollow tube consisting of the mouth, pharynx, esophagus, stomach, small intestine, and large intestine, in which digestion and absorption of nutrients occurs.

gene A length of DNA containing the information needed to synthesize RNA, which may translate into a polypeptide sequence.

gene expression The process by which the information coded in a gene is used to synthesize a product, either a protein or a molecule of RNA.

generally recognized as safe (GRAS) A group of chemical additives that are generally recognized as safe based on their long-standing presence in the food supply without obvious harmful effects.

genetically modified organism (GMO) An organism whose genetic material has been altered using genetic engineering techniques.

genetic engineering A set of techniques used to manipulate DNA for the purpose of changing the characteristics of an organism or creating a new product.

germ The embryo or sprouting portion of a kernel of grain. It contains oil, protein, fiber, and vitamins.

gestation The time between conception and birth, which lasts about nine months (or about 40 weeks) in humans.

gestational diabetes mellitus A consistently elevated blood glucose level that develops during pregnancy and returns to normal after delivery.

gestational hypertension The development of hypertension after the 20th week of pregnancy.

ghrelin A peptide hormone produced by the stomach that stimulates food intake.

ginseng An herb used in traditional Chinese medicine; claims are made that it improves athletic performance and increases sexual potency.

gleaning The act of collecting the crops left in farmers' fields after they have been commercially harvested or collecting those that were not harvested for economic reasons.

glomerulus A ball of capillaries in the nephron that filters blood during urine formation.

glucagon A hormone secreted by the pancreas that stimulates the breakdown of liver glycogen and the synthesis of glucose to increase blood sugar.

glucogenic amino acid An amino acid that can be used to synthesize glucose through gluconeogenesis.

gluconeogenesis The synthesis of glucose from simple noncarbohydrate molecules. Amino acids from protein are the primary source of carbons for glucose synthesis.

glucose A monosaccharide that is the primary form of carbohydrate used to provide energy in the body. It is the sugar referred to as blood sugar.

glutamic acid A nonessential amino acid that is found in protein and in monosodium glutamate (MSG).

glutathione peroxidase A selenium-containing enzyme that protects cells from oxidative damage by neutralizing peroxides.

gluten-related disorders A group of conditions that cause reactions to gluten-containing foods. Includes celiac disease, non-celiac gluten sensitivity, and wheat allergy.

glycemic index A ranking of the effect on blood glucose of a food of a certain carbohydrate content relative to an equal amount of carbohydrate from a reference food such as white bread or glucose.

glycemic load An index of the glycemic response that occurs after eating specific foods. It is calculated by multiplying a food's glycemic index by the amount of available carbohydrate in a serving of the food.

glycemic response The rate, magnitude, and duration of the rise in blood glucose that occurs after a particular food or meal is consumed.

glycerol A 3-carbon molecule that forms the backbone of triglycerides and phosphoglycerides; also used as a humectant in food.

glycogen A carbohydrate made of many glucose molecules linked together in a highly branched structure. It is the storage form of carbohydrate in animals.

glycogenesis The conversion of glucose to glycogen for storage.

glycogen supercompensation or **carbohydrate loading** A regimen designed to maximize muscle glycogen stores before an athletic event.

glycolysis (also called **anaerobic metabolism).** Metabolic reactions in the cytosol of the cell that split glucose into two 3-carbon pyruvate molecules, yielding two ATP molecules.

goiter An enlargement of the thyroid gland caused by a deficiency of iodine.

goitrogens Substances that interfere with the utilization of iodine or the function of the thyroid gland.

gout Disorder in which crystals of uric acid deposit in and around joints, especially of the big toe and foot, causing pain and arthritis.

GRAS See Generally recognized as safe.

growth hormone A hormone secreted by the pituitary gland that stimulates growth.

H

Hazard Analysis Critical Control Point (HACCP) A food safety system that focuses on identifying, preventing, and eliminating hazards that could cause foodborne illness.

health claim A statement made about the relationship between a nutrient or food and a disease or health condition.

Healthy Eating Index A system developed to evaluate the adequacy of the American diet. It is based on how well a person's diet meets current dietary recommendations.

Healthy People Initiative A set of national health promotion and disease prevention objectives for the U.S. population.

heart attack A condition in which an artery supplying blood to the heart becomes blocked, cutting off blood flow and hence oxygen and nutrients to a segment of the heart muscle, resulting in tissue death.

heartburn A burning sensation in the chest caused when acidic stomach contents leak into the esophagus through the gastroesophageal sphincter.

heat cramp A muscle cramp caused by an imbalance of sodium and potassium at the muscle cell membrane as a result of excessive exercise without adequate fluid and electrolyte replacement.

heat exhaustion Low blood pressure, rapid pulse, fainting, and sweating caused when dehydration decreases blood volume so much that blood can no longer both cool the body and provide oxygen to the muscles.

heat-related illnesses Conditions, including heat cramps, heat exhaustion, and heat stroke, that can occur due to an unfavorable combination of exercise, hydration status, and climatic conditions.

heat stroke Elevated body temperature as a result of fluid loss and the failure of the temperature regulatory center of the brain.

Heimlich maneuver A procedure used to dislodge an object blocking an air passage; involves the application of sharp, firm pressure to the abdomen just below the rib cage.

heme iron A readily absorbed form of iron found in animal products that is chemically associated with proteins such as hemoglobin and myoglobin.

hemochromatosis An inherited condition that results in increased iron absorption.

hemoglobin An iron-containing protein in red blood cells that binds oxygen and transports it through the bloodstream to cells.
hemolytic anemia Anemia that results when red blood cells break open.
hemorrhoids Swollen veins in the anal or rectal area.
hemosiderin An insoluble iron storage compound that stores iron when the amount of iron in the body exceeds the storage capacity of ferritin.
hepatic portal circulation The system of blood vessels that collects nutrient-laden blood from the digestive organs and delivers it to the liver.
hepatic portal vein The vein that transports blood from the GI tract to the liver.
hepatitis Inflammation of the liver.
hepcidin A peptide hormone produced by the liver that regulates the absorption of iron across the intestinal mucosa.
herb The leaves, flowers, stems, roots, seeds, or any other part of a nonwoody seed-bearing plant that dies down to the ground after flowering.
herbicide Chemical pesticide that is sprayed on crops in the field to control weeds.
heterocyclic amines (HCAs) A class of carcinogenic substances produced when there is incomplete combustion of amino acids during the cooking of meats—such as when meat is charred.
high-density lipoprotein (HDL) A lipoprotein that picks up cholesterol from cells and transports it to the liver so that it can be eliminated from the body. A high level of HDL decreases the risk of cardiovascular disease.
high-fructose corn syrup A sweetener made from corn syrup that is composed of approximately half fructose and half glucose.
high-quality or **complete dietary protein** Protein that provides essential amino acids in the proportions needed to support protein synthesis.
histamine A substance produced by cells of the immune system as part of a nonspecific response that leads to inflammation.
homeostasis A physiological state in which a stable internal body environment is maintained.
homocysteine A sulfur-containing amino acid that is produced from the metabolism of methionine. Elevated blood levels increase the risk of cardiovascular disease.
hormone Chemical messenger that is produced in one location, released into the blood, and elicits responses at other locations in the body.
hormone-sensitive lipase An enzyme present in adipocytes that responds to chemical signals by breaking down triglycerides into fatty acids and glycerol for release into the bloodstream.
human intervention study or **clinical trial** A study of a population in which there is an experimental manipulation of some members of the population; observations and measurements are made to determine the effects of this manipulation.
humectant A substance added to foods to retain moisture.
hunger A desire to consume food that is triggered by internal physiological signals. Also refers to recurrent involuntary lack of food that over time may lead to malnutrition.
hybridization The process of cross-fertilizing two related plants with the goal of producing an offspring that has the desirable characteristics of both parent plants.
hydrochloric acid An acid secreted by the gastric glands of the stomach to aid in digestion.
hydrogenation The process whereby hydrogen atoms are added to the carbon–carbon double bonds of unsaturated fatty acids, making them more saturated.
hydrolysis reaction Chemical reaction that breaks large molecules into smaller ones by adding water.
hydrolyzed protein See Protein hydrolysate.
hydroxyapatite A crystalline compound composed of calcium and phosphorus that is deposited in the protein matrix of bone to give it strength and rigidity.
hypercarotenemia A condition in which carotenoids accumulate in the adipose tissue, causing the skin to appear yellow-orange.
hyperemesis gravidarum A severe and intractable form of nausea and vomiting that affects some women during pregnancy.
hypertension Blood pressure that is consistently elevated to 140/90 millimeters of mercury (mm Hg) or greater.
hypertensive disorders of pregnancy High blood pressure during pregnancy that is due to chronic hypertension, gestational hypertension, preeclampsia–eclampsia, or preeclampsia superimposed on chronic hypertension.
hypertrophy An increase in the size of a muscle or organ.
hypoglycemia A low blood glucose level, usually below 40 to 50 mg of glucose per 100 mL of blood.
hyponatremia Abnormally low concentration of sodium in the blood.
hypothalamus The region of the brain that monitors and regulates conditions and activities in the body, including food intake and energy expenditure.
hypothermia A condition in which body temperature drops below normal. Hypothermia depresses the central nervous system, resulting in the inability to shiver, sleepiness, and eventually coma and death.
hypothesis An educated guess made to explain an observation or to answer a question.

I

ileocecal valve The structure that separates the ileum of the small intestine from the large intestine.
ileum The 11-foot segment of the small intestine that connects the jejunum with the large intestine.
impaired glucose tolerance See pre-diabetes.
implantation The process by which the developing embryo embeds in the uterine lining.
incomplete dietary protein Protein that is deficient in one or more essential amino acids relative to body needs.
indirect calorimetry A method of estimating energy use that compares the amount of oxygen consumed to the amount of carbon dioxide expired.
indirect food additive A substance that is expected to enter food unintentionally during manufacturing or from packaging. Indirect food additives are regulated by the FDA.
infant mortality rate The number of deaths during the first year of life per 1000 live births.
inflammation The response of a part of the body to injury that increases blood flow with an influx of white blood cells and other chemical substances to facilitate healing. It is characterized by swelling, heat, redness, pain, and loss of function.
inorganic molecule A molecule that contains no carbon–hydrogen bonds.
insensible losses Fluid losses that are not perceived by the senses, such as evaporation of water through the skin and lungs.
insoluble fiber Fiber that, for the most part, does not dissolve in water and is less readily broken down by the microbiota of the large intestine. It includes cellulose, some hemicelluloses, and lignin.
insulin A hormone secreted by the pancreas that allows the uptake of glucose by muscle and adipose tissue and has other metabolic effects such as stimulating protein and fat synthesis and the synthesis of glycogen in liver and muscle.
integrated pest management (IPM) A method of agricultural pest control that

integrates nonchemical and chemical techniques.

intermediate-density lipoprotein (IDL) A lipoprotein produced by the removal of triglycerides from VLDLs, most of which are then transformed to LDLs.

International Unit (IU) A unit of measure that has been used to express requirements of some vitamins.

interstitial fluid The portion of the extracellular fluid located in the spaces between the cells of body tissues.

intervention study See Clinical trial.

intestinal microbiota or **intestinal microflora** Microorganisms that inhabit the gastrointestinal tract.

intestinal microflora See intestinal microbiota.

intracellular fluid The fluid located inside cells.

intrinsic factor A protein produced in the stomach that is needed for the absorption of adequate amounts of vitamin B_{12}.

ion An atom or molecule that has a positive or negative charge because it has unequal numbers of protons and electrons.

iron deficiency anemia An iron deficiency disease that occurs when the oxygen-carrying capacity of the blood is decreased because not enough iron is available to make adequate amounts of hemoglobin.

irradiation A process, also called *cold pasteurization*, that exposes foods to radiation to kill contaminating organisms and retard ripening and spoilage of fruits and vegetables.

isomers Molecules with the same molecular formula but a different arrangement of the atoms.

isotopes Alternative forms of an element that have different atomic masses and may or may not be radioactive.

J

jejunum The 8-foot-long section of the small intestine lying between the duodenum and the ileum.

K

keratin A hard protein that makes up hair and nails.

keratomalacia Softening, drying, and ulceration of the cornea resulting from vitamin A deficiency.

Keshan disease A type of heart disease that occurs in areas of China where the soil is very low in selenium. It is believed to be caused by a combination of viral infection and selenium deficiency.

ketoacidosis A life-threatening increase in the acidity of the blood due to high ketone levels.

ketogenic amino acid An amino acid that breaks down to form acetyl-CoA and thus contributes to ketone synthesis.

ketones or **ketone bodies** Molecules formed in the liver when the amount of carbohydrate is not sufficient to completely metabolize the two-carbon units produced from fat breakdown.

ketosis High levels of ketones in the blood.

kilocalorie (kcal, kcalorie) The unit of heat used to express the amount of energy provided by foods. It is the amount of heat required to raise the temperature of 1 kg of water 1 degree Celsius (1 kcal = 4.18 kJ).

kilojoule (kJ, kjoule) A unit of work that can be used to express energy intake and energy output. It is the amount of work required to move an object weighing 1 kg a distance of 1 meter under the force of gravity (1 kJ = 0.24 kcal).

kinky hair disease See Menkes disease

kwashiorkor A form of protein-energy malnutrition in which only protein is deficient.

L

lactase An enzyme located in the microvilli of the small intestine that breaks the disaccharide lactose into glucose and galactose.

lactation Milk production and secretion.

lacteal A small lymph vessel in the intestine that absorbs and transports the products of fat digestion.

lactic acid A compound produced from the breakdown of glucose in the absence of oxygen.

lacto-ovo vegetarian A dietary pattern that includes no animal flesh but does include eggs and dairy products such as milk and cheese.

lactose A disaccharide that is formed by linking galactose and glucose. It is commonly known as milk sugar.

lactose intolerance A condition in which people have digestive symptoms such as intestinal gas, bloating, and diarrhea after dairy products are consumed.

lacto-vegetarian A dietary pattern that includes no animal flesh or eggs but does include dairy products.

large for gestational age A term used to describe an infant weighing more than 4 kg (8.8 lb) at birth.

large intestine The portion of the gastrointestinal tract that includes the colon and rectum; some water and vitamins are absorbed, and bacteria act on food residues here.

laxative A substance that eases the excretion of feces.

LDL receptor A protein on the surface of cells that binds to LDL particles and allows their contents to be taken up for use by the cell.

lean body mass or **fat-free mass** Body mass attributed to nonfat body components such as bone, muscle, and internal organs.

leavening agent A substance added to food that causes the production of gas, resulting in an increase in volume.

lecithin A phosphoglyceride composed of a glycerol backbone, two fatty acids, a phosphate group, and a molecule of choline.

legumes Plants in the pea or bean family that produce an elongated pod containing large starchy seeds. Green peas, kidney beans, and peanuts are legumes.

leptin A peptide hormone produced by adipocytes that signals information about the amount of body fat.

leptin receptors Proteins that bind the hormone leptin. In response to this binding, they trigger events that cause changes in food intake and energy expenditure.

letdown A hormonal reflex triggered by an infant's suckling that causes milk to be released from the milk glands and flow through the duct system to the nipple.

life expectancy The average length of life for a population of individuals.

life span The maximum age to which members of a species can live.

lignin An insoluble fiber responsible for the hard woody nature of plant stems.

limiting amino acid The essential amino acid that is available in the lowest concentration in relation to the body's needs.

linoleic acid An essential omega-6 essential fatty acid with 18 carbons and 2 double bonds.

lipase A fat-digesting enzyme.

lipid bilayer Two layers of phosphoglyceride molecules oriented so that the fat-soluble fatty acid tails are sandwiched between the water-soluble phosphate-containing heads.

lipids A group of organic molecules, most of which do not dissolve in water. They include fatty acids, triglycerides, phospholipids, and sterols.

lipoprotein A particle containing a core of triglycerides and cholesterol surrounded by a shell of protein, phospholipids, and cholesterol that transports lipids in blood and lymph.

lipoprotein lipase An enzyme that breaks down triglycerides into fatty acids and glycerol; attached to the cell membranes of cells that line the blood vessels.

liposuction A procedure that suctions out adipose tissue from under the skin; used to decrease the size of local fat deposits such as on the abdomen or hips.

longevity The duration of an individual's life.

longitudinal data Information obtained by repeatedly sampling the same individuals in a population over time.

low birth weight A term used to describe an infant weighing less than 2.5 kg (5.5 lb) at birth.

low-density lipoprotein (LDL) A lipoprotein that transports cholesterol to cells. Elevated LDL cholesterol increases the risk of cardiovascular disease.

lumen The inside cavity of a tube, such as the gastrointestinal tract.

lutein A carotenoid found in corn and green peppers that has no vitamin A activity but provides some protection against macular degeneration.

lycopene A carotenoid that gives the red color to tomatoes. It cannot be converted to vitamin A.

lymphatic system The system of vessels, organs, and tissues that drains excess fluid from the spaces between cells, transports fat-soluble substances from the digestive tract, and contributes to immune function.

lymph vessel A tubular component of the lymphatic system that carries fluid away from body tissues. Lymph vessels in the intestine are known as lacteals and can transport large particles such as the products of fat digestion.

lysozyme An enzyme in saliva, tears, and sweat that is capable of destroying certain types of bacteria.

M

macrocytes Larger-than-normal mature red blood cells that have a shortened life span.

macrocytic anemia A reduction in the blood's hemoglobin content and hence capacity to carry oxygen that is characterized by abnormally large red blood cells.

macronutrient A nutrient needed by the body in large amounts. These include water and the energy-yielding nutrients: carbohydrates, lipids, and proteins.

macular degeneration Degeneration of a portion of the retina that results in a loss of visual detail and blindness.

mad cow disease The common name for bovine spongiform encephalaopathy (BSE), a cattle disease that causes the brain to degenerate.

major mineral A mineral needed in the diet in an amount greater than 100 mg/day or present in the body in an amount greater than 0.01% of body weight.

malignancy A mass of cells showing uncontrolled growth, a tendency to invade and damage surrounding tissues, and an ability to seed daughter growths to sites remote from the original growth.

malnutrition Any condition resulting from an energy or nutrient intake either above or below that which is optimal.

maltase An enzyme found in the microvilli of the small intestine that breaks maltose into two molecules of glucose.

maltose A disaccharide made up of two molecules of glucose. It is formed in the intestines during starch digestion.

marasmus A form of protein-energy malnutrition in which a deficiency of energy in the diet causes severe body wasting.

maximal oxygen consumption See aerobic capacity.

maximum heart rate The maximum number of beats per minute that the heart can attain. It declines with age.

megaloblasts Large, immature red blood cells that are formed when developing red blood cells are unable to divide normally.

melatonin A hormone involved in regulating the body's cycles of sleep and wakefulness. Levels decline with age. Supplements are claimed to boost antioxidant defenses, improve immune function, and slow aging.

menaquinones The forms of vitamin K synthesized by bacteria and found in animals.

menarche The onset of menstruation, which occurs normally between the ages of 10 and 15 years.

Menkes disease An inherited defect in copper transport that results in copper deficiency. Symptoms include poor growth, neurological symptoms, and coarse, kinky, colorless, brittle hair. Also called kinky hair disease.

menopause The physiological changes that mark the end of a woman's capacity to bear children.

menstruation The cyclic discharge of the uterine lining that, in the absence of pregnancy, occurs about every four weeks during the reproductive years of female humans.

metabolic pathway A series of chemical reactions inside a living organism that results in the transformation of one molecule into another.

metabolic syndrome A collection of health risks, including high blood pressure, altered blood lipids, high blood glucose, and a large waist circumference, that increases the chance of developing heart disease, stroke, and diabetes. The condition is also called Syndrome X, insulin resistance syndrome, or dysmetabolic syndrome.

metabolism The sum of all chemical reactions that take place in a living organism.

metallothionein A group of proteins that bind metals. One such protein binds zinc and copper in intestinal cells, limiting their absorption into the blood.

methionine An essential sulfur-containing amino acid found in protein.

methyl group A chemical group consisting of a carbon atom bound to three hydrogen atoms.

micelles Particles formed in the small intestine when the products of fat digestion are surrounded by bile acids. They facilitate the absorption of fat.

microbe An organism too small to be seen without a microscope; also called a microorganism.

microorganism An organism such as a bacterium, too small to be seen without a microscope.

micronutrient A nutrient needed by the body in small amounts. These include vitamins and minerals.

microsomal ethanol-oxidizing system (MEOS) A liver enzyme system located in microsomes that converts alcohol to acetaldehyde. Activity increases with increases in alcohol consumption.

microvilli or **brush border** Minute brush-like projections on the mucosal cell membrane that increase the absorptive surface area in the small intestine and contain some digestive enzymes.

mineral In nutrition, an element needed by the body in small amounts for structure and to regulate chemical reactions and body processes.

miscarriage or **spontaneous abortion** Interruption of pregnancy prior to the seventh month.

mitochondrion (mitochondria) Cellular organelle that is responsible for providing energy in the form of ATP for cellular activities.

modified-atmosphere packaging (MAP) A preservation technique used to prolong the shelf life of processed or fresh food by changing the gases surrounding the food in the package.

mold Multicellular fungi that form a filamentous branching growth.

molecular biology The study of cellular function at the molecular level.

molecule A group of two or more atoms of the same or different elements bonded together.

monoglyceride or **monoacylglycerol** A molecule of glycerol with one fatty acid attached.

monosaccharide A carbohydrate made up of a single sugar unit.

monosodium glutamate (MSG) An additive used as a flavor enhancer, commonly used in Chinese food; made up of the amino acid glutamate bound to sodium.
monounsaturated fatty acid A fatty acid that contains one carbon–carbon double bond.
morbidity The incidence or state of disease or disability.
morbid obesity or **extreme obesity** A body mass index greater than 40 kg/m^2.
morning sickness Nausea and vomiting that affects many women during the first few months of pregnancy and in some women can continue throughout the pregnancy.
mRNA (messenger RNA) A molecule that carries the information in a gene to ribosomes in the cytosol so polypeptides can be synthesized.
MSG symptom complex Symptoms of headache, flushing, tingling, burning sensations, and chest pain reported by some individuals after consuming monosodium glutamate (MSG); commonly referred to as Chinese restaurant syndrome.
mucosa The layer of epithelial tissue lining the GI tract and other body cavities.
mucus A viscous fluid secreted by glands in the GI tract and other parts of the body. It acts to lubricate, moisten, and protect cells from harsh environments.
muscle dysmorphia A psychological disorder characterized by a negative body image and an obcessive desire to have a more muscular physique.
muscle-strengthening exercise Activities that are specifically designed to increase muscle strength, endurance, and size; also called strength training or resistance exercise.
mutagen Any agent that causes a change in a cell's genetic material.
mutations Changes in DNA caused by chemical or physical agents.
myelin A soft, white fatty substance that covers nerve fibers and aids in nerve transmission.
myocardial infarction Heart attack.
myoglobin An iron-containing protein in muscle cells that binds oxygen.

N

National Health and Nutrition Examination Survey (NHANES) A survey that collects information about the health and nutritional status of individuals in the population.
nephron The functional unit of the kidney that performs the job of filtering the blood and maintaining fluid balance.
net protein utilization A measure of protein quality determined by comparing the amount of nitrogen retained in the body with the amount eaten in the diet.
neural tube The portion of the embryo that develops into the brain and spinal cord.
neural tube closure A developmental event in which neural tissue forms a groove and the sides fold together to form a tube; is completed about 28 days after fertilization.
neural tube defects Birth defects caused by abnormal development of the neural tube, the portion of the embryo that gives rise to the central nervous system.
neuromotor exercise A type of exercise training that incorporates motor skills such as balance, coordination, agility, and proprioception.
neurotransmitter A chemical substance produced by a nerve cell that can stimulate or inhibit another cell.
niacin A B vitamin, also called vitamin B_3, that is needed in energy metabolism.
niacin equivalents (NEs) The measure used to express the amount of niacin present in food, including that which can be made from its precursor, tryptophan. One NE is equal to 1 mg of niacin or 60 mg of tryptophan.
nicotinamide A form of niacin.
nicotinamide adenine dinucleotide (NAD) and **nicotinamide adenine dinucleotide phosphate (NADP)** The active coenzyme forms of niacin that can pick up and donate hydrogens and electrons. They are important in the transfer of electrons to oxygen in cellular respiration and in many synthetic reactions.
nicotinic acid A form of niacin.
night blindness The inability of the eye to adapt to reduced light, causing poor vision in dim light.
nitrogen balance The amount of nitrogen consumed in the diet compared with the amount excreted by the body over a given period.
nitrosamines Carcinogenic compounds produced by reactions between nitrites and amino acids.
non-celiac gluten sensitivity (NCGS) A condition that causes symptoms similar to those seen with celiac disease when gluten is consumed, but not the same antibodies and intestinal damage seen in celiac disease.
nonessential or **dispensable amino acid** An amino acid that can be synthesized by the human body in sufficient amounts to meet the body's needs.
nonexercise activity thermogenesis (NEAT) The energy expended for everything we do other than sleeping, eating, or sports-like exercise.
nonheme iron A poorly absorbed form of iron found in both plant and animal foods that is not part of the iron complex found in hemoglobin and myoglobin.
nucleus The central core of an atom, consisting of positively charged protons and electrically neutral neutrons. In cells, it is an organelle containing DNA.
nursing bottle syndrome Extreme tooth decay in the upper teeth resulting from putting a child to bed with a bottle containing milk or other sweet liquids.
nutrient density An evaluation of the nutrient content of a food in comparison to the calories it provides.
nutrients Substances in foods that provide energy and structure and help regulate body processes.
nutrigenetics The science of the effect of genes on dietary response.
nutrigenomics The science of the effect of nutrients and bioactive compounds on gene expression.
nutrition A science that studies the interactions between living organisms and food.
nutritional assessment An evaluation used to determine the nutritional status of individuals or groups for the purpose of identifying nutritional needs and planning personal health-care or community programs to meet those needs.
nutritional genomics The study of how our genes affect the impact of nutrients or other food components on health (nutrigenetics) and how nutrients affect the activity of our genes (nutrigenomics).
nutritional status State of health as it is influenced by the intake and utilization of nutrients.
nutrition transition A series of changes in diet, physical activity, health, and nutrition that occurs as poor countries become more prosperous.

O

obese Having excess body fat. Obesity is defined as a body mass index (a ratio of weight to height squared) of 30 kg/m^2 or greater.
obesity genes Genes that code for proteins involved in the regulation of food intake, energy expenditure, or the deposition of body fat. When they are abnormal, the result is abnormal amounts of body fat.
oil A lipid that is liquid at room temperature.
oleic acid A monounsaturated fatty acid with 18 carbons.

oligosaccharides Short-chain carbohydrates containing 3 to 10 sugar units.
omega-3 fatty acid A fatty acid containing a carbon–carbon double bond between the third and fourth carbons from the omega end.
omega-6 fatty acid A fatty acid containing a carbon–carbon double bond between the sixth and seventh carbons from the omega end.
opsin A protein in the retina of the eye involved in the visual cycle.
organ A discrete structure composed of more than one tissue that performs a specialized function.
organelles Cellular organs that carry out specific metabolic functions.
organic food Food that is produced, processed, and handled in accordance with the standards of the USDA National Organic Program.
organic molecule A molecule that contains carbon bonded to hydrogen.
osmosis The passive movement of water across a semipermeable membrane in a direction that will equalize the concentration of dissolved substances on both sides.
osteoarthritis The form of arthritis common in the elderly that is characterized by a wearing down of the joint surfaces and pain when the joint is moved.
osteoblast A type of cell responsible for the deposition of bone.
osteoclast A type of cell responsible for bone breakdown.
osteomalacia A vitamin D deficiency disease in adults characterized by a loss of minerals from bones. It causes bone pain, muscle aches, and an increase in bone fractures.
osteoporosis A bone disorder characterized by a decrease in bone mass, an increase in bone fragility, and an increased risk of fractures.
overload principle The concept that the body will adapt to the stresses placed on it.
overnutrition Poor nutritional status resulting from an energy or nutrient intake in excess of that which is optimal for health.
overtraining syndrome A collection of emotional, behavioral, and physical symptoms that occurs when the amount and intensity of exercise exceed an athlete's capacity to recover.
overweight Being too heavy for one's height. It is defined as having a body mass index (a ratio of weight to height squared) of 25 to 29.9 kg/m^2.
oviduct or **fallopian tube** Narrow duct leading from the ovary to the uterus.
oxalate An organic acid found in spinach and other leafy green vegetables that can bind minerals and decrease their absorption.
oxaloacetate A 4-carbon compound derived from carbohydrate that combines with acetyl-CoA in the first step of the citric acid cycle.
oxidation The loss of electrons.
oxidation-reduction reaction A reaction in which electrons are transferred from a donor molecule (the reducing agent) to an acceptor molecule (the oxidizing agent).
oxidative damage Damage caused by highly reactive oxygen molecules that steal electrons from other compounds, causing changes in structure and function.
oxidative stress A condition that occurs when there are more reactive oxygen molecules than can be neutralized by available antioxidant defenses.
oxidized Refers to a compound that has lost an electron or undergone a chemical reaction with oxygen.
oxidized LDL cholesterol A substance formed when the cholesterol in LDL particles is oxidized by reactive oxygen molecules. It is key in the development of atherosclerosis because it contributes to the inflammatory process.
oxytocin A hormone produced by the posterior pituitary gland that acts on the uterus to cause uterine contractions and on the breast to cause the movement of milk into the secretory ducts that lead to the nipple.

P

palmitic acid A saturated fatty acid containing 16 carbons.
pancreas An organ that secretes digestive enzymes and bicarbonate ions into the small intestine during digestion.
pancreatic amylase Starch-digesting enzyme produced in the pancreas and released into the small intestine.
pancreatic juice The secretion of the pancreas containing bicarbonate to neutralize acid and enzymes for the digestion of carbohydrates, fats, and proteins.
pantothenic acid A B vitamin needed in energy metabolism.
parasites Organisms that live at the expense of others.
parathyroid hormone (PTH) A hormone secreted by the parathyroid gland that increases blood calcium levels.
parietal cells Large cells in the stomach lining that produce and secrete intrinsic factor and hydrochloric acid.
partially hydrogenated oil A liquid oil that has undergone a process that adds hydrogen atoms to the carbon–carbon bonds of unsaturated fatty acids to make the oil more solid and/or increase the shelf life of the product.
pasteurization The process of heating food products to kill disease-causing organisms.
pathogen A biological agent that causes disease.
PA (physical activity) value A numerical value associated with activity level that is a variable in the EER equations used to calculate energy needs.
peak bone mass The maximum bone density attained at any time in life, usually occurring in young adulthood.
peer review Review of the design and validity of a research experiment by experts in the field of study who did not participate in the research.
pellagra A disease resulting from a deficiency of niacin that causes dermatitis, diarrhea, dementia, and, if not treated, death.
pepsin A protein-digesting enzyme produced by the gastric glands. It is secreted in the gastric juice in an inactive form and activated by acid in the stomach.
pepsinogen An inactive protein-digesting enzyme produced by gastric glands and activated to pepsin by acid in the stomach.
peptic ulcers An open sore in the lining of the stomach, esophagus, or small intestine.
peptide Two or more amino acids joined by peptide bonds.
peptide bond A chemical linkage between the amino group of one amino acid and the acid group of another.
peptide YY An appetite-suppressing peptide hormone that is released from the gastrointestinal tract after a meal.
periodontal disease A degeneration of the area surrounding the teeth, specifically the gum and supporting bone.
peristalsis Coordinated muscular contractions that move food through the GI tract.
peroxide A reactive chemical that can form free radicals and cause cellular damage.
pernicious anemia A macrocytic anemia resulting from vitamin B_{12} deficiency that occurs when dietary vitamin B_{12} cannot be absorbed due to a lack of intrinsic factor.
pesticide Any substance or mixture of substances intended to prevent, destroy, repel, or mitigate insect, animal, plant, fungal, or microbial pests.
pesticide tolerances The maximum amount of pesticide residues that may legally remain in or on foods marketed in the United States; set by the EPA.
pH A measure of the level of acidity or alkalinity of a solution.
pharynx A funnel-shaped opening that connects the nasal passages and mouth to the respiratory passages and esophagus. It is a common passageway for food and air and is responsible for swallowing.

phenylalanine An essential amino acid found in protein that cannot be metabolized by individuals with phenylketonuria (PKU).

phenylketone The product of phenylalanine breakdown produced when phenylalanine cannot be converted to tyrosine; when blood levels get too high, brain damage may result.

phenylketonuria (PKU) An inherited disease in which the body cannot metabolize the amino acid phenylalanine. If the disease is untreated, toxic by-products called *phenylketones* accumulate in the blood and interfere with brain development.

phosphoglyceride A type of phospholipid consisting of a glycerol molecule, two fatty acids, and a phosphate group.

phospholipid A type of lipid that contains phosphorus. The most common is a phosphoglyceride.

photosynthesis The metabolic process by which plants trap energy from the sun and use it to make sugars from carbon dioxide and water.

phylloquinone The form of vitamin K found in plants.

physical frailty Impairment in function and reduction in physiological reserves severe enough to cause limitations in the basic activities of daily living.

phytate or **phytic acid** A phosphorus storage compound found in seeds and grains that can bind minerals and decrease their absorption.

phytochemical A substance found in plant foods (*phyto-* means plant) that is not an essential nutrient but may have health-promoting properties.

phytoestrogen An estrogen-like molecule produced by plants.

phytosterol Compound produced by plants that has a structure similar to cholesterol.

pica A persistent ingestion of nonnutritive, nonfood items.

placebo A fake medicine or supplement that is indistinguishable in appearance from the real thing. It is used to disguise the control and experimental groups in an experiment.

placenta An organ produced from both maternal and embryonic tissues. It secretes hormones, transfers nutrients and oxygen from the mother's blood to the fetus, and removes wastes.

plant sterols and **stanols** Compounds found in plant cell membranes that resemble cholesterol in structure. They can lower blood cholesterol by competing with cholesterol for absorption in the gastrointestinal tract.

plasma The liquid portion of the blood that remains when the blood cells are removed.

plasmid A loop of bacterial DNA that is independent of the bacterial chromosome.

platelet A cell fragment found in blood that is involved in blood clotting.

polar Used to describe a molecule that has a positive charge at one end and a negative charge at the other.

polychlorinated biphenyls (PCBs) Carcinogenic industrial compounds that have found their way into the environment and, subsequently, the food supply. Repeated ingestion causes them to accumulate in biological tissues over time.

polycyclic aromatic hydrocarbons (PAHs) A class of carcinogenic substances produced during cooking when there is incomplete combustion of organic materials—such as when fat drips on a grill.

polypeptide A chain consisting of many amino acids linked by peptide bonds.

polysaccharide A carbohydrate made up of many sugar units.

polyunsaturated fatty acid A fatty acid that contains two or more carbon-carbon double bonds.

postmenopausal bone loss Accelerated bone loss that occurs in women for about 5 to 10 years surrounding menopause.

prebiotic A substance that passes undigested into the colon and stimulates the growth and/or activity of certain types of bacteria.

prediabetes or **impaired glucose tolerance** A fasting blood glucose level above the normal range but not high enough to be classified as diabetes.

preeclampsia A condition characterized by an increase in body weight, elevated blood pressure, protein in the urine, and edema. It can progress to **eclampsia**, which causes seizures and can be life threatening to mother and fetus.

premenstrual syndrome (PMS) A syndrome of mood swings, food cravings, bloating, tension and depression, headaches, acne, and anxiety, among other symptoms, that results from the hormonal changes during the days prior to menstruation.

preservative A compound that extends the shelf life of a product by retarding chemical, physical, or microbiological changes.

preterm or **premature** An infant born before 37 weeks of gestation.

prion A pathogenic protein that is the cause of degenerative brain diseases called *spongiform encephalopathies*. Prion is short for proteinaceous infectious particle.

prior-sanctioned substances Refers to substances that the FDA or the USDA had determined were safe for use in a specific food prior to the 1958 Food Additives Amendment.

probiotic Live bacteria that, when consumed, live temporarily in the colon and confer health benefits on the host.

processed food A food that has been specially treated or changed from its natural state.

progesterone A female sex hormone needed for development and function of the uterus and mammary glands.

programmed cell death The death of cells at specific predictable times.

prolactin A hormone secreted by the anterior pituitary that acts on the milk-producing glands in the breast to stimulate and sustain milk production.

pro-oxidant A substance that promotes oxidative damage.

protease A protein-digesting enzyme.

protein An organic molecule made up of one or more intertwining chains of amino acids.

protein complementation The process of combining proteins from different sources so that they collectively provide the proportions of amino acids required to meet the body's needs.

protein digestibility-corrected amino acid score (PDCAAS) A measure of protein quality that reflects a protein's digestibility as well as the proportions of amino acids it provides.

protein-energy malnutrition (PEM) A condition characterized by wasting and an increased susceptibility to infection that results from the long-term consumption of insufficient amounts of energy and protein to meet needs.

protein hydrolysate or **hydrolyzed protein** A mixture of amino acids or amino acids and polypeptides that results when a protein is completely or partially broken down by treatment with acid or enzymes.

protein quality A measure of how efficiently a protein in the diet can be used to make body proteins.

protein-sparing modified fast A very-low-calorie diet with a high proportion of protein; designed to maximize the loss of fat and minimize the loss of protein from the body.

protein turnover The continuous synthesis and breakdown of body proteins.

prothrombin A blood protein required for blood clotting.

provitamin or **vitamin precursor** A compound that can be converted into the active form of a vitamin in the body.
puberty A period of rapid growth and physical changes that ends in the attainment of sexual maturity.
purging Behaviors such as self-induced vomiting and misuse of laxatives, diuretics, or enemas to rid the body of calories.
pyloric sphincter A muscular valve that helps regulate the rate at which food leaves the stomach and enters the small intestine.
pyridoxal phosphate The major coenzyme form of vitamin B_6 that functions in more than 100 enzymatic reactions, many of which involve amino acid metabolism.
pyridoxine The chemical term for vitamin B_6.
pyruvate A 3-carbon molecule produced when glucose is broken down by glycolysis.

Q

qualified health claims Health claims on food labels that have been approved based on emerging but not well-established evidence for a relationship between a food, food component, or dietary supplement and reduced risk of a disease or health-related condition.

R

raffinose An oligosaccharide found in beans and other legumes that cannot be digested by human enzymes in the stomach and small intestine.
recombinant DNA DNA that has been formed by joining DNA from different sources.
Recommended Dietary Allowances (RDAs) Intakes that are sufficient to meet the nutrient needs of almost all healthy people in a specific life-stage and gender group.
rectum The portion of the large intestine that connects the colon and anus.
reduced Refers to a substance that has gained an electron.
Reference Daily Intakes (RDIs) Reference values established for vitamins and minerals that are based on the highest amount of each nutrient recommended for any adult age group by the 1968 RDAs.
refined Refers to foods that have undergone processing that removes various components of the original food.
renewable resources Resources that are restored and replaced by natural processes and that can therefore be used forever.
renin An enzyme produced by the kidneys that converts angiotensinogen to angiotensin I.
reserve capacity The amount of functional capacity that an organ has above and beyond what is needed to sustain life.
resistant starch Starch that is classified as fiber because it escapes digestion in the small intestine of healthy people.
respiratory system Organ system that includes the lungs and air passageways involved in the exchange of oxygen from the environment with carbon dioxide waste from cells by way of the bloodstream.
resting energy expenditure (REE) or **resting metabolic rate (RMR)** Terms used when an estimate of basal metabolism is determined by measuring energy utilization after five to six hours without food or activity.
resting heart rate The number of times that the heart beats per minute while a person is at rest.
restriction enzyme A bacterial enzyme used in genetic engineering that has the ability to cut DNA in a specific location.
retinal The aldehyde form of vitamin A, which is needed for the visual cycle.
retinoic acid The acid form of vitamin A, which is needed for cell differentiation, growth, and reproduction.
retinoids The chemical forms of preformed vitamin A: retinol, retinal, and retinoic acid.
retinol The alcohol form of vitamin A, which circulates in the blood and can be interconverted with retinal.
retinol activity equivalent (RAE) The amount of retinol, β-carotene, α-carotene, or β-cryptoxanthin that provides vitamin A activity equal to 1 μg of retinol.
retinol-binding protein A protein that is necessary to transport vitamin A from the liver to other tissues.
rhodopsin A light-absorbing compound found in the retina of the eye that is composed of the protein opsin loosely bound to retinal.
riboflavin A B vitamin, also called vitamin B_2, that is needed in energy metabolism.
ribose The 5-carbon sugar that is part of the structure of RNA.
ribosome The cell organelle where protein synthesis occurs.
rickets A vitamin D deficiency disease in children that is characterized by poor bone development because of inadequate calcium absorption.
risk-benefit analysis The process of weighing the risk of a substance against the benefits it provides; if the risk is small and the benefits great, small amounts of this substance may be acceptable.
risk factor A characteristic or circumstance that is associated with the occurrence of a particular disease.
RNA (ribonucleic acid) A single-stranded nucleic acid. It carries information in DNA from the nucleus to the cytosol, is a component of ribosomes, and delivers amino acids for protein synthesis.

S

saccharin An alternative sweetener that contains no energy and is about 300 times sweeter than sugar.
saliva A watery fluid produced and secreted into the mouth by the salivary glands. It contains lubricants, enzymes, and other substances.
salivary amylase An enzyme secreted by the salivary glands that breaks down starch.
salivary glands The internal structures located at the sides of and below the face and in front of the ears; secrete saliva into the mouth.
Salmonella A bacterium that commonly causes food-borne illness.
sarcopenia Progressive decrease in skeletal muscle mass and strength that occurs with age.
satiety The feeling of fullness and satisfaction, caused by food consumption, that eliminates the desire to eat.
saturated fatty acid A fatty acid in which the carbon atoms are bound to as many hydrogen atoms as possible and that therefore contains no carbon–carbon double bonds.
scavenger receptor A protein on the surface of macrophages that binds to oxidized LDL cholesterol and allows it to be taken up by the cell.
scientific method The general approach of science that is used to explain observations about the world around us.
scurvy A vitamin C deficiency disease characterized by bleeding gums, tooth loss, joint pain, bleeding into the skin and mucous membranes, and fatigue.
secondary lactose intolerance Lactase deficiency that occurs as a result of disease and may resolve after the disease has ended.
secretin A hormone released by the duodenum that signals the release of pancreatic juice rich in bicarbonate ions and stimulates the liver to secrete bile into the gallbladder.
segmentation Rhythmic local constrictions of the intestine that mix food with digestive juices and speed absorption by repeatedly moving the food mass over the intestinal wall.
selective breeding Techniques to selectively control mating in plants and

animals for the purpose of producing organisms that better serve human needs.

selectively permeable Describes a membrane or barrier that will allow some substances to pass freely but will restrict the passage of others.

selenoproteins Proteins that contain selenium as a structural component of their amino acids. Selenium is most often found as selenocysteine, which contains an atom of selenium in place of the sulfur atom.

self-esteem The general attitude of approval or disapproval that people have about themselves.

semiessential amino acid See Conditionally essential amino acid.

semivegetarian One who occasionally eats meat, fish, and poultry as well as eggs and dairy products.

serotonin A neurotransmitter that functions in the sleep center of the brain.

set point A level at which body fat or body weight seems to resist change despite changes in energy intake or output.

sickle cell disease An inherited disease in which hemoglobin structure is altered. Red blood cells containing the altered hemoglobin are sickle-shaped; rupture easily, causing anemia; and block small blood vessels, causing inflammation and pain.

significant scientific agreement Refers to a means of authorizing health claims on food labels that involves extensive review of the scientific evidence.

simple carbohydrates A class of carbohydrates, known as sugars, that includes monosaccharides and disaccharides.

simple diffusion The unassisted movement of substances from an area of higher concentration to an area of lower concentration. No energy is required.

simple sugar See Simple carbohydrates.

single-blind study An experiment in which either the study participants or the researchers are unaware of which participants are in a control or an experimental group.

skinfold thickness A measurement of subcutaneous fat used to estimate total body fat.

small for gestational age A term used to describe a baby born at term weighing less than 2.5 kg (5.5 lb).

small intestine A tube-shaped organ of the digestive tract where digestion of ingested food is completed and most of the absorption occurs.

sodium bicarbonate A compound that is part of an important buffer system in pancreatic juice and in the bloodstream. Also used as an ergogenic aid.

sodium-potassium ATPase or **sodium-potassium pump** An energy-requiring protein pump in the cell membrane that pumps sodium out of the cell and potassium into the cell.

sodium-potassium pump see sodium-potassium ATPase.

soluble fiber Fiber that dissolves in water or absorbs water to form viscous solutions and is readily broken down by the intestinal microbiota. It includes pectins, gums, and some hemicelluloses.

solutes Dissolved substances.

solution A solvent containing a dissolved substance.

solvent A fluid in which one or more substances dissolve.

sorbitol A sugar alcohol formed from the sugar sorbose; used as a sweetener or humectant in food.

sphincter A muscular valve that helps control the flow of materials in the GI tract.

spina bifida A type of neural tube defect resulting from the incorrect development of the spinal cord that can leave the spinal cord exposed.

spontaneous abortion or **miscarriage** Interruption of pregnancy prior to the seventh month.

spore A dormant state of some bacteria that is resistant to heat but can germinate and produce a new organism when environmental conditions are favorable.

sports anemia Reduced hemoglobin levels that occur as part of a beneficial adaptation to aerobic exercise in which expanded plasma volume dilutes red blood cells.

stachyose An oligosaccharide found in beans and other legumes that cannot be digested by human enzymes in the stomach and small intestine.

standards of identity Regulations that define the allowable ingredients, composition, and other characteristics of foods.

starch A carbohydrate made of many glucose molecules linked in straight or branching chains. The bonds that hold the glucose molecules together can be broken by human digestive enzymes.

starvation A severe reduction in nutrient and energy intake that impairs health and eventually causes death. It is the most extreme form of malnutrition.

stearic acid An 18-carbon saturated fatty acid that, unlike other saturated fats, does not raise blood cholesterol levels.

steroid hormone A hormone that is made from cholesterol; includes the male and female sex hormones.

sterol A type of lipid with a structure composed of multiple chemical rings.

stroke A blood clot or bleeding in the brain that causes brain tissue death.

stroke volume The volume of blood pumped by each beat of the heart.

structure/function claims Claims on food and supplement labels that describe the role of a nutrient or dietary ingredient in maintaining normal structure or function in humans.

stunting A decrease in linear growth rate that is an indicator of nutritional well-being in populations of children.

subcutaneous fat Adipose tissue that is located under the skin.

subsistence crop A crop that is grown as food for a farmer's family, with little or nothing left over to sell.

sucralose An alternative sweetener made from sucrose that is about 600 times sweeter than sucrose; trichlorogalactosucrose. It is heat stable, and so can be used in baked products.

sucrase An enzyme in the microvilli of the small intestine that breaks sucrose into glucose and fructose.

sucrose A disaccharide that is formed by linking fructose and glucose. It is commonly known as table sugar or white sugar.

sudden infant death syndrome (SIDS) or **crib death** The unexplained death of an infant, usually during sleep.

sugar alcohols Sweeteners that are structurally related to sugars but provide less energy than monosaccharides and disaccharides because they are not well absorbed.

sulfites Sulfur-containing compounds used as preservatives to prevent oxidation in dried fruits and vegetables and to prevent bacterial growth in wine.

superoxide dismutase (SOD) An enzyme that protects the cell by neutralizing damaging superoxide free radicals. One form of the enzyme requires zinc and copper for activity, and another form requires manganese.

superoxide radical A type of reactive oxygen molecule that can form free radicals leading to oxidative damage. They can be neutralized by the enzyme superoxide dismutase.

sustainable agriculture Agricultural methods that maintain soil productivity and a healthy ecological balance while having minimal long-term impacts.

T

tannin A substance found in tea and some grains that can bind minerals and decrease their absorption.

teratogen A substance that can cause birth defects.

testosterone A steroid hormone secreted by the testes that is involved in the

maintenance and development of male sex organs and secondary sex characteristics.

theory An explanation based on scientific study and reasoning.

thermic effect of food (TEF) or **diet-induced thermogenesis** The energy required for the digestion of food and the absorption, metabolism, and storage of nutrients. It is equal to approximately 10% of daily energy intake.

thiamin A B vitamin, also called vitamin B_1, that is needed in energy metabolism.

thiamin pyrophosphate The active coenzyme form of thiamin. It is the predominant form found inside cells, where it aids reactions in which a carbon-containing group is lost as CO_2.

threshold effect A reaction that occurs at a certain level of ingestion and increases as the dose increases. Below that level there is no reaction.

thyroid gland A gland located in the neck that produces thyroid hormones and calcitonin.

thyroid hormones Hormones produced by the thyroid gland that regulate metabolic rate.

thyroid-stimulating hormone (TSH) A hormone that stimulates the synthesis and secretion of thyroid hormones from the thyroid gland.

tocopherol The chemical name for vitamin E.

Tolerable Upper Intake Levels (ULs) Maximum daily intakes that are unlikely to pose a risk of adverse health effects to almost all individuals in the specified life-stage and gender group.

total energy expenditure (TEE) The sum of the energy used for basal metabolism, activity, processing of food, deposition of new tissue, and production of milk.

total parenteral nutrition (TPN) A technique for nourishing an individual by providing all needed nutrients directly into the circulatory system.

toxin A substance that can cause harm at some level of exposure.

trabecular or **spongy bone** The type of bone forming the inner spongy lattice that lines the bone marrow cavity and supports the cortical shell.

trace mineral or **trace element** A mineral required in the diet in an amount of 100 mg or less per day or present in the body in an amount of 0.01% of body weight or less.

transamination The process by which an amino group from one amino acid is transferred to a carbon compound to form a new amino acid.

transcription The process of copying the information in DNA to a molecule of mRNA.

***trans* fatty acid** An unsaturated fatty acid in which the hydrogen atoms are on opposite sides of the double bond.

transferrin An iron transport protein in the blood.

transgenic organism An organism with a gene or group of genes intentionally transferred from another species or breed.

transit time The time between the ingestion of food and the elimination of the solid waste from that food.

translation The process of translating the mRNA code into the amino acid sequence of a polypeptide chain.

treatment groups See Experimental groups.

triacylglycerol See Triglyceride.

trichinosis The disease caused by infection with the roundworm *Trichinella spiralis* after eating undercooked contaminated pork or game meats; the juvenile form of this roundworm migrates to the muscles and causes flu-like symptoms and muscle pain and weakness.

triglyceride (triacylglycerol) The major form of lipid in food and in the body. Each consists of three fatty acids attached to a glycerol molecule.

trimester A term used to describe each third, or three-month period, of a pregnancy.

tripeptide Three amino acids linked by peptide bonds.

tropical oils A term used in the popular press to refer to the saturated oils—coconut, palm, and palm kernel oil—that are derived from plants grown in tropical regions.

trypsin A protein-digesting enzyme that is secreted from the pancreas in inactive form and activated in the small intestine.

tuber The starchy underground storage organ of plants.

tumor initiator A substance that causes mutations and therefore may predispose a cell to becoming cancerous.

tumor promoter A substance that contributes to cancer formation by stimulating cells to divide.

twenty-four-hour recall (24-hour recall) A method of assessing dietary intake in which a trained interviewer helps an individual remember what he or she ate during the previous day.

type 1 diabetes A form of diabetes that is caused by the autoimmune destruction of insulin-producing cells in the pancreas, usually leading to absolute insulin deficiency; previously known as insulin-dependent diabetes or juvenile-onset diabetes.

type 2 diabetes A form of diabetes characterized by insulin resistance and relative insulin deficiency; previously known as non–insulin-dependent diabetes or adult-onset diabetes.

U

ubiquinone A compound that transports electrons in the electron transport chain but that is not essential in the diet; also called coenzyme Q.

UL See Tolerable Upper Intake Level (UL).

ulcer An open sore.

undernutrition Any condition resulting from an energy or nutrient intake below that which meets nutritional needs.

underwater weighing A technique that uses the difference between body weight underwater and body weight on land to estimate body density and calculate body composition.

underweight A body mass index of less than 18.5 kg/m^2, or a body weight 10% or more below the desirable body weight standard.

unsaturated fatty acid A fatty acid that contains one or more carbon-carbon double bonds.

urea A nitrogen-containing waste product formed from the breakdown of amino acids that is excreted in the urine.

U.S. Department of Agriculture (USDA) U.S. government agency responsible for monitoring the safety and wholesomeness of meat, poultry, and eggs.

V

variable A factor or condition that is changed in an experimental setting.

vegan diet A pattern of food intake that eliminates all animal products.

vegetarian diet A pattern of food intake that includes plant-based foods and eliminates some or all foods of animal origin.

vein A vessel that carries blood toward the heart.

venule A small vein that drains blood from capillaries and passes it to larger veins for return to the heart.

very low birth weight A term used to describe an infant weighing less than 1.5 kg (3.3 lb) at birth.

very-low-calorie diet A weight-loss diet that provides fewer than 800 kcal/day.

very-low-density lipoprotein (VLDL) A lipoprotein assembled by the liver that carries lipids from the liver and delivers triglycerides to body cells.

villi (villus) Finger-like protrusions of the lining of the small intestine that participate in the digestion and absorption of nutrients.

virus An infective agent that typically consists of a nucleic acid molecule in a protein coat, is not visible under an ordinary microscope, and depends on cells for its metabolic and reproductive needs.

visceral fat Adipose tissue that is located in the abdomen around the body's internal organs.

vitamins Organic compounds needed in the diet in small amounts to promote and regulate the chemical reactions and processes needed for growth, reproduction, and maintenance of health.

W

warfarin An anticoagulant drug that acts by inhibiting the action of vitamin K. It is a derivative of dicumarol; also used as rat poison.

water intoxication A condition that occurs when a person drinks enough water to significantly lower the concentration of sodium in the blood.

water-soluble vitamins Vitamins that dissolve in water.

weight cycling or **yo-yo dieting** The repeated loss and regain of body weight.

Wernicke–Korsakoff syndrome A form of thiamin deficiency associated with alcohol abuse that is characterized by mental confusion, disorientation, loss of memory, and a staggering gait.

whole grain The entire kernel of grain including the bran layers, the germ, and the endosperm.

Wilson's disease An inherited defect in copper metabolism that leads to excessive accumulation of copper in the body and can cause neurological symptoms and liver disease.

X

xanthan gum A plant extract used as a stabilizer in processed foods.

xanthomas Cholesterol deposits that form under the skin.

xerophthalmia A spectrum of eye conditions resulting from vitamin A deficiency that may lead to blindness. An early symptom is night blindness, and as deficiency worsens, lack of mucus leaves the eye dry and vulnerable to cracking and infection.

xylitol The sugar alcohol formed from the sugar xylose; used in sugarless gum.

Y

yo-yo diet syndrome See Weight cycling.

Z

zeaxanthin A carotenoid found in corn and green peppers that has no vitamin A activity but provides some protection against macular degeneration.

zoochemicals Substances found in animal foods (*zoo-* means animal) that are not essential nutrients but may have health-promoting properties.

zygote The cell produced by the union of sperm and ovum during fertilization.

References

Chapter 1

1. American Dietetic Association. *Nutrition and You: Trends 2011*. Available online at http://www.eatright.org/nutritiontrends. Accessed December 6, 2014.
2. Smith, L. P., Ng, S. W., and Popkin, B. M. Trends in US home food preparation and consumption: Analysis of national nutrition surveys and time use studies from 1965–1966 to 2007–2008. *J Nutr* 12:45–55, 2013.
3. U.S. Department of Agriculture, Economic Research Service. *Food Away from Home.* Available online at http://www.ers.usda.gov/topics/food-choices-health/food-consumption-demand/food-away-from-home.aspx. Accessed December 4, 2014.
4. Todd, J. E., Mancino, L., and Lin, B.-H. *The Impact of Food Away from Home on Adult Diet Quality* (ERR-90). Washington, DC: U.S. Department of Agriculture, Economic Research Service, February 2010.
5. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.
6. Piernas, C., and Popkin, B. Snacking increased among US adults between 1977 and 2007. *J Nutr* 140:325–332, 2010.
7. Ogden, C. L., Carroll, M. D., Kit, B. K., and Flagel, K. M. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA* 311:806–814, 2014.
8. Mesirow, M. S., and Welsh, J. A. Changing beverage consumption patterns have resulted in fewer liquid calories in the diets of US children: National Health and Nutrition Examination Survey 2001–2010. *J Acad Nutr Diet* 115:559–566, 2015.
9. Xu, J., Kochanek, K. D., Murphy, S. L., and Arias, E. Mortality in the United States, 2012. *NCHS Data Brief* Dec (168):1—8, 2014.
10. Centers for Disease Control and Prevention. *Chronic Disease Prevention and Health Promotion.* Available online at http://www.cdc.gov/chronicdisease/overview. Accessed January 17, 2015.
11. U.S. Burden of Disease Collaborators. The state of US health, 1990–2010: Burden of diseases, injuries, and risk factors. *JAMA* 310:591–608, 2013.
12. U.S. Department of Health and Human Services. *Physical Activity Guidelines for Americans, 2008*. Available online at http://www.health.gov/paguidelines/guidelines. Accessed January 17, 2015.
13. Council for Responsible Nutrition. *New Survey Reveals High Percentage of U.S. Population Take Dietary Supplements—and with High Confidence.* Available online at http://www.crnusa.org/CRNPR14-CRNCCSurvey103014.html. Accessed July 15, 2015.
14. Kaput, J. Nutrigenomics—2006 update. *Clin Chem Lab Med* 45:279–287, 2007.
15. Bouchard, C., and Ordovas, J. M. Fundamentals of nutrigenetics and nutrigenomics. *Prog Mol Biol Transl Sci* 108:1–15, 2012.
16. Simopoulos, A. P. Nutrigenetics/nutrigenomics. *Annu Rev Public Health* 31:53–68, 2010.
17. Fenech, M., El-Sohemy, A., Cahill, L., et al. Nutrigenetics and nutrigenomics: Viewpoints on the current status and applications in nutrition research and practice. *J Nutrigenet Nutrigenomics* 4:69–89, 2011.
18. Sherwood, D. Nutrigenomics: Public concerns and commercial interests. *Agro Food Ind Hi Tech* 17:56–57, 2006.
19. Lampe, J. W. For debate: Investment in nutrigenomics will advance the role of nutrition in public health. *Cancer Epidemiol Biomarkers Prev* 15:2329–2330, 2006.
20. Wallace, H. Your diet tailored to your genes: Preventing diseases or misleading marketing? *GeneWatch UK*, January 2006.
21. Epstein, F. H. Cardiovascular disease epidemiology: A journey from the past into the future. *Circulation* 93:1755–1764, 1996.
22. Keys, A., Taylor, H. L., Blackburn, H., et al. Coronary heart disease among Minnesota business and professional men followed fifteen years. *Circulation* 28:381–495, 1963.
23. Menotti, A., Kromhout, D., Blackburn, H., et al. Food intake patterns and 25-year mortality from coronary heart disease: Cross-cultural correlations in the Seven Countries Study. *Eur J Epidemiol* 15:507–515, 1999.
24. The diet and all-causes death rate in the Seven Countries Study. *Lancet* 2:58–61, 1981.
25. Keys, A. *Seven Countries: A Multivariate Analysis of Death and Coronary Heart Disease*. Commonwealth Fund. Cambridge, MA: Harvard University Press, 1980.
26. Achievements in public health, 1900–1999: Decline in deaths from heart disease and stroke—United States, 1900–1999. *MMWR Morb Mortal Wkly Rep* 48:649–656, 1999.

Chapter 2

1. Davis, C., and Saltos, E. Dietary recommendations and how they have changed over time. In *America's Eating Habits: Changes and Consequences* (Agriculture Information Bulletin No. 10). U.S. Department of Agriculture, Economic Research Service, Food and Rural Economics Division. Available online at http://www.ers.usda.gov/media/91022/aib750b_1_.pdf. Accessed January 11, 2015.
2. National Research Council, Food and Nutrition Board. *Recommended Dietary Allowances*, 10th ed. Washington, DC: National Academies Press, 1989.
3. U.S. Senate. *Eating in America: Dietary Goals for the United States*. Report of the Select Committee on Nutrition and Human Needs. Cambridge, MA: MIT Press, 1977.

4. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.

5. Finkelstein, E. A., Trogdon, J. G., Cohen, J. W., and Dietz, W. Annual medical spending attributable to obesity: Payer- and service-specific estimates. *Health Affairs* 28:w822–w831, 2009.

6. Cawley, J., and Maclean, J. C. Unfit for service: The implications of rising obesity for U.S. military recruitment. *Health Econ* 21:1348–1366, 2012.

7. Vaitheeswaran, V. Economist debates: Food policy. *The Economist*, December 8, 2009.

8. World Health Organization. *Dietary Recommendations/ Nutrient Requirements*. Available online at http://www.who.int/nutrition/topics/nutrecomm/en. Accessed January 11, 2015.

9. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride*. Washington, DC: National Academies Press, 1997.

10. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B-6, Folate, Vitamin B-12, Pantothenic Acid, Biotin, and Choline*. Washington, DC: National Academies Press, 1998.

11. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein, and Amino Acids*. Washington, DC: National Academies Press, 2002, 2005.

12. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Available online at http://health.gov/dietaryguidelines/2015-scientific-report/pdfs/scientific-report-of-the-2015-dietary-guidelines-advisory-committee.pdf. Accessed January 17, 2016.

13. Centers for Disease Control and Prevention. *CDC Estimates of Foodborne Illness in the United States*. Available online at http://www.cdc.gov/foodborneburden. Accessed January 24, 2015.

14. U.S. Department of Agriculture. *MyPlate*. Available online at http://www.choosemyplate.gov. Accessed January 2015.

15. U.S. Food and Drug Administration. *Proposed Changes to the Nutrition Facts Label*. Available online at http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm385663.htm. Accessed July 15, 2015.

16. Council for Responsible Nutrition. *New Survey Reveals High Percentage of U.S. Population Take Dietary Supplements—and with High Confidence*. Available online at http://www.crnusa.org/CRNPR14-CRNCCSurvey103014.html. Accessed July 15, 2015.

17. U.S. Food and Drug Administration. *Dietary Supplement Labeling Guide. Guidance for Food Industry, a Dietary Supplement Labeling Guide*, April 2005. Available at http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/DietarySupplements/ucm2006823.htm. Accessed January 12, 2015.

18. U.S. Food and Drug Administration. Current good manufacturing practice in manufacturing, packaging, labeling, or holding operations for dietary supplements; final rule. *Fed Regist* 72:34752–34958, June 25, 2007. Available online at http://www.gpo.gov/fdsys/pkg/FR-2007-06-25/html/07-3039.htm. Accessed January 12, 2015.

19. U.S. Pharmacopeia. *USP Verified Dietary Supplements*. Available online at http://www.usp.org/usp-verification-services/usp-verified-dietary-supplements. Accessed January 12, 2015.

20. U.S. Food and Drug Administration. *Food Labeling Guide*. Available online at http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm2006828.htm. Accessed January 12, 2015.

21. U.S. Department of Agriculture, Food Safety and Inspection Service. Nutrition labeling of single-ingredient products and ground or chopped meat and poultry products; final rule. *Fed Regist* 75:82147–82167, December 29, 2010.

22. U.S. Food and Drug Administration. Food labeling; nutrition labeling of standard menu items in restaurants and similar retail food establishments; final rule. *Fed Regist* 79:71155–71259, December 1, 2014.

23. U.S. Food and Drug Administration. Food labeling; calorie labeling of articles of food in vending machines; final rule. *Fed Regist* 79:71259–71293, December 1, 2014.

24. Office of Disease Prevention and Health Promotion. *2020 Topics and objective—Objectives A–Z*. Available online at http://www.healthypeople.gov/2020/topicsobjectives2020. Accessed March 14, 2015.

25. American Diabetes Association. *Choose Your Foods: Food Lists for Diabetes*. Alexandria, VA: American Dietetic Association, 2014.

26. Gemming, L., Jiang, Y., Swinburn, B., et al. Under-reporting remains a key limitation of self-reported dietary intake: An analysis of the 2008/09 New Zealand Adult Nutrition Survey. *Eur J Clin Nutr* 68:259–264, 2014.

27. Guenther, P. M., Kirkpatrick, S. I., Reedy, J., et al. The Healthy Eating Index 2010 is a valid and reliable measure of diet quality according to the 2010 Dietary Guidelines for Americans. *J Nutr* 144:399–407, 2014.

28. U.S. Department of Agriculture. *USDA National Nutrient Database for Standard Reference*. Available online at https://www.nal.usda.gov/fnic/foodcomp/search. Accessed January 14, 2015.

29. Ogden, C. L. Carroll, M. D., Kit, B. K., and Flegal, K. M. Prevalence of childhood and adult obesity in the United States, 2011– 2012. *JAMA* 311:806–814, 2014.

30. Centers for Disease Control and Prevention. *Key statistics from NHANES*. Available online at http://wwwn.cdc.gov/nchs/nhanes/bibliography/key_statistics.aspx. Accessed January 14, 2015.

31. Centers for Disease Control and Prevention. *Continuous NHANES Web Tutorial, NHANES Sample Design*. Available online at http://www.cdc.gov/nchs/tutorials/nhanes/surveydesign/SampleDesign/intro.htm. Accessed January 14, 2015.

Chapter 3

1. de Moreno de LeBlanc, A., and LeBlanc, J. G. Effect of probiotic administration on the intestinal microbiota, current knowledge and potential applications. *World J Gastroenterol* 20:16518–16528, 2014.
2. Power, S. E., O'Toole, P. W., Stanton, C., et al. Intestinal microbiota, diet and health. *Br J Nutr* 111:387–402, 2014.
3. O'Connor, E. M. The role of gut microbiota in nutritional status. *Curr Opin Clin Nutr Metab Care* 16:509–516, 2013.
4. Sellers, R. S., and Morton, D. The colon: From banal to brilliant. *Toxicol Pathol* 42:67–81, 2014.
5. Chan, Y. K., Estaki, M., and Gibson, D. L. Clinical consequences of diet-induced dysbiosis. *Ann Nutr Metab* 63(suppl 2):28–40, 2013.
6. Salonen, A., and de Vos, W. M. Impact of diet on human intestinal microbiota and health. *Annu Rev Food Sci Technol* 5:239–262, 2014.
7. Sicherer, S. H., and Sampson, H. A. Food allergy: Epidemiology, pathogenesis, diagnosis, and treatment. *J Allergy Clin Immunol* 133:291–307, 2014.
8. National Institute of Diabetes and Digestive and Kidney Diseases. *Celiac Disease*. Available online at http://www.niddk.nih.gov/health-information/health-topics/digestive-diseases/celiac-disease/Pages/facts.aspx#other. Accessed December 13, 2014.
9. Rubio-Tapia, A., Ludvigsson, J. F., Brantner, T. L., et al. The prevalence of celiac disease in the United States. *Am J Gastroenterol* 107:1538–1545, 2012.
10. Ludvigsson, J. F., Leffler, D. A., Bai, J. C., et al. The Oslo definitions for coeliac disease and related terms. *Gut* 62:43–52, 2013.
11. Czaja-Bulsa, G. Non coeliac gluten sensitivity—A new disease with gluten intolerance. *Clin Nutr* 34:189–194, 2015.
12. Mansueto, P., Seidita, A., D'Alcamo, A., and Carroccio, A. Non-celiac gluten sensitivity: Literature review. *J Am Coll Nutr* 33:39–54, 2014.
13. Biesiekierski, J. R., Muir, J. G., and Gibson, P. R. Is gluten a cause of gastrointestinal symptoms in people without celiac disease? *Curr Allergy Asthma Rep* 13:631–638, 2013.
14. Catassi, C., Bai, J. C., Bonaz, B., et al. Non-celiac gluten sensitivity: The new frontier of gluten related disorders. *Nutrients* 5:3839–3853, 2013.
15. Rubio-Tapia, A., Ludvigsson, J. F., Brantner, T. L., et al. The prevalence of celiac disease in the United States. *Am J Gastroenterol* 107:1538–1545, 2012.
16. National Foundation for Celiac Awareness. *Nonceliac Gluten Sensitivity*. Available online at http://www.celiaccentral.org/non-celiac-gluten-sensitivity. Accessed December 27, 2014.
17. Konturek, S. J., Konturek, P. C., Konturek, J. W., et al. *Helicobacter pylori* and its involvement in gastritis and peptic ulcer formation. *J Physiol Pharmacol* 57(suppl 3): 29–50, 2006.
18. U.S. Food and Drug Administration. *OTC Drug Facts Label*. Available online at http://www.fda.gov/Drugs/ResourcesForYou/Consumers/ucm143551.htm. Accessed July 17, 2015.
19. Lynch, N. A. Helicobacter pylori *and Ulcers: A paradigm revised*. Available online at http://www.faseb.org/portals/0/pdfs/opa/pylori.pdf. Accessed July 17, 2015.
20. Marshall, B. J., and Warren, J. R. Unidentified curved bacilli on gastric epithelium in active chronic gastritis. *Lancet* 1:1311–1315, 1984.
21. Marshall, B. J., Armstrong, J. A., McGechie, D. B., and Glancy, R. J. Attempt to fulfill Koch's postulates for pyloric *Campylobacter*. *Med J Aust* 142:436–439, 1985.
22. McGee, D. J., and Mobley, H. L. T. Mechanisms of *Helicobacter pylori* infection: Bacterial factors. *Curr Top Microbiol Immunol* 241:156–180, 1999.
23. Joseph, I. M., and Kirschner, D. A. Model for the study of *Helicobacter pylori* interaction with human gastric acid secretion. *J Theor Biol* 228:55–80, 2004.
24. U.S. Department of Health and Human Services, National Institutes of Diabetes and Digestive and Kidney Diseases. *Definition and Facts for Peptic Ulcer Disease.* Available online at http://www.niddk.nih.gov/health-information/health-topics/digestive-diseases/peptic-ulcer/Pages/definition-facts.aspx Accessed July 17, 2015.
25. Fock, K. M. Review article: The epidemiology and prevention of gastric cancer. *Aliment Pharmacol Ther* 40:250–260, 2014.
26. Marieb, E. N., and Hoehn, K. *Human Anatomy and Physiology,* 9th ed. Menlo Park, CA: Pearson, 2013.

Chapter 4

1. Gross, L. S., Li, L., Ford, E. S., and Liu, S. Increased consumption of refined carbohydrates and the epidemic of type 2 diabetes in the United States: An ecologic assessment. *Am J Clin Nutr* 79:774–779, 2004.
2. Jensen, H. H., and Beghin, J. C. U.S. sweetener consumption trends and dietary guidelines. *Iowa Ag Rev* 11:10–11, 2005.
3. Bray, G. A., Nielsen, S. J., and Popkin, B. M. Consumption of high-fructose corn syrup in beverages may play a role in the epidemic of obesity. *Am J Clin Nutr* 79:537–543, 2004.
4. Gaby, A. R. Adverse effects of dietary fructose. *Altern Med Rev* 10:294–306, 2005.
5. Stanhope, K. L., Schwarz, J. M., Keim, N. L., et al. Consuming fructose-sweetened, not glucose-sweetened, beverages increases visceral adiposity and lipids and decreases insulin sensitivity in overweight/obese humans. *J Clin Invest* 119: 1322–1334, 2009.
6. Tappy, L., and Lê, K. A. Metabolic effects of fructose and the worldwide increase in obesity. *Physiol Rev* 90:23–46, 2010.
7. Klurfeld, D. M., Foreyt, J., Angelopoulos, T. J., and Rippe, J. M. Lack of evidence for high fructose corn syrup as the cause of the obesity epidemic. *Int J Obes (Lond)* 37:771–773, 2013.
8. Rippe, J. M., and Angelopoulos, T. J. Sucrose, high-fructose corn syrup, and fructose, their metabolism and potential health effects: What do we really know? *Adv Nutr* 4:236–245, 2013.

9. Pan, A., and Hu, F. B. Effects of carbohydrates on satiety: Differences between liquid and solid food. *Curr Opin Clin Nutr Metab Care* 14:385–390, 2011.

10. Ebbeling, C. B. Sugar-sweetened beverages and body weight. *Curr Opin Lipidol* 25:1–7, 2014.

11. Bray, G. A. Energy and fructose from beverages sweetened with sugar or high-fructose corn syrup pose a health risk for some people. *Adv Nutr* 4:220–225, 2013.

12. Bocarsly, M. E., Powell, E. S., Avena, N. M., and Hoebel, B. G. High-fructose corn syrup causes characteristics of obesity in rats: Increased body weight, body fat and triglyceride levels. *Pharmacol Biochem Behav* 97:101–106, 2010.

13. Lowndes, J., Kawiecki, D., Pardo, S., et al. The effects of four hypocaloric diets containing different levels of sucrose or high fructose corn syrup on weight loss and related parameters. *Nutr J* 11:55, 2012.

14. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.

15. Newburg, D. S., Ruiz-Palacios, G. M., and Morrow, A. L. Human milk glycans protect infants against enteric pathogens. *Annu Rev Nutr* 25:37–58, 2005.

16. Slavin, J. Fiber and prebiotics: Mechanisms and health benefits. *Nutrients* 5:1417–1435, 2013.

17. Mudgil, D., and Barak, S. Composition, properties and health benefits of indigestible carbohydrate polymers as dietary fiber: A review. *Int J Biol Macromol* 61:1–6, 2013.

18. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids.* Washington, DC: National Academies Press, 2002, 2005.

19. National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), National Institutes of Health of the U.S. Department of Health and Human Services. *Lactose intolerance*. Available online at http://digestive.niddk.nih.gov/ddiseases/pubs/lactoseintolerance. Accessed December 7, 2014.

20. Suchy, F. J., Brannon, P. M., Carpenter, T. O., et al. National Institutes of Health Consensus Development Conference: Lactose intolerance and health. *Ann Intern Med* 152:792–796, 2010.

21. National Library of Medicine, National Institutes of Health. *Lactose intolerance*. Available online at http://ghr.nlm.nih.gov/condition/lactose-intolerance. Accessed December 18, 2014.

22. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Available online at http://health.gov/dietaryguidelines/2015-scientific-report/pdfs/scientific-report-of-the-2015-dietary-guidelines-advisory-committee.pdf. Accessed January 17, 2016.

23. Slavin, J. L. Position of the American Dietetic Association: Health implications of dietary fiber. *J Am Diet Assoc* 108: 1716–1731, 2008. Erratum in *J Am Diet Assoc* 109:350, 2009.

24. Burkitt, D. P., Walker, A. R. P., and Painter, N. S. Dietary fiber and disease. *JAMA* 229:1068–1074, 1974.

25. Saulnier, D. M., Kolida, S., and Gibson, G. R. Microbiology of the human intestinal tract and approaches for its dietary modulation. *Curr Pharm Des* 15:1403–1414, 2009.

26. Rose, D. J., DeMeo, M. T., Keshavarzian, A., and Hamaker, B. R. Influence of dietary fiber on inflammatory bowel disease and colon cancer: Importance of fermentation pattern. *Nutr Rev* 65:51–62, 2007.

27. Clark, M. J., and Slavin, J. L. The effect of fiber on satiety and food intake: A systematic review. *J Am Coll Nutr* 32:200–211, 2013.

28. Willett, W. C., and Stampfer, M. J. Current evidence on healthy eating. *Annu Rev Public Health* 34:77–95, 2013.

29. Centers for Disease Control and Prevention. *National Diabetes Statistics Report: Estimates of Diabetes and Its Burden in the United States, 2014*. Atlanta, GA: U.S. Department of Health and Human Services, 2014.

30. Aune, D., Norat, T., Romundstad, P., and Vatten, L. J. Whole grain and refined grain consumption and the risk of type 2 diabetes: A systematic review and dose-response meta-analysis of cohort studies. *Eur J Epidemiol* 28:845–858, 2013.

31. National Diabetes Education Program. Available online at http://ndep.nih.gov. Accessed December 7, 2014.

32. Asano, R. Y., Sales, M. M., Browne, R. A., et al. Acute effects of physical exercise in type 2 diabetes: A review. *World J Diabetes* 5:659–665, 2014.

33. American Diabetes Association. Standards of medical care in diabetes—2015. *Diabetes Care* 38:S1–S90, 2015.

34. Nordqvist, C. All about diabetes: Discovery of insulin. *Medical News Today*, April 2010. Available online at http://www.medicalnewstoday.com/info/diabetes/discoveryofinsulin.php. Accessed December 9, 2014.

35. Zuger, A. Rediscovering the first miracle drug. *New York Times*, October 4, 2010. Available online at http://www.nytimes.com/2010/10/05/health/05insulin.html?pagewanted=all. Accessed December 9, 2014.

36. Nobel Prize website. *The Nobel Prize in Physiology or Medicine 1923*, February 19, 2012. Available online at http://www.nobelprize.org/nobel_prizes/medicine/laureates/1923. Accessed December 9, 2014.

37. National Institutes of Health, National Institute of Dental and Craniofacial Research. *Dental Caries (Tooth Decay) in Adults (Age 20 to 64).* Available online at http://www.nidcr.nih.gov/DataStatistics/FindDataByTopic/DentalCaries/DentalCariesAdults20to64.htm. Accessed December 7, 2014.

38. Bradshaw, D. J., and Lynch, R. J. Diet and the microbial aetiology of dental caries: New paradigms. *Int Dent J* 63 (suppl 2):64–72, 2013.

39. Du, H., van der A, D. L., Boshuizen, H. C., et al. Dietary fiber and subsequent changes in body weight and waist circumference in European men and women. *Am J Clin Nutr* 91:329–336, 2010.

40. Tucker, L. A., and Thomas, K. S. Increasing total fiber intake reduces risk of weight and fat gains in women. *J Nutr* 139:576–581, 2009.

41. Matarese, L. E., and Pories, W. J. Adult weight loss diets: Metabolic effects and outcomes. *Nutr Clin Pract* 29:759–767, 2014.

42. Ha, V., Jayalath, V. H., Cozma, A. I., et al. Fructose-containing sugars, blood pressure, and cardiometabolic risk: A critical review. *Curr Hypertens Rep* 15:281–297, 2013.

43. Bernstein, A. M., Titgemeier, B., Kirkpatrick, K., et al. Major cereal grain fibers and psyllium in relation to cardiovascular health. *Nutrients* 5:1471–1487, 2013.

44. Gunness, P., and Gidley, M. J. Mechanisms underlying the cholesterol-lowering properties of soluble dietary fibre polysaccharides. *Food Funct* 1:149–155, 2010.

45. Institute of Medicine Food and Nutrition Board. *Dietary Reference Intakes: Proposed Definition of Dietary Fiber.* Washington, DC: National Academies Press, 2001.

46. Strate, L. L. Lifestyle factors and the course of diverticular disease. *Dig Dis* 30:35–45, 2012.

47. National Digestive Disease Information Clearinghouse. *Diverticulosis and diverticulitis.* Available online at http://digestive.niddk.nih.gov/ddiseases/pubs/diverticulosis. Accessed December 9, 2014.

48. Aune, D., Chan, D. S., Lau, R., et al. Dietary fibre, whole grains, and risk of colorectal cancer: Systematic review and dose-response meta-analysis of prospective studies. *BMJ* 343:d6617, 2011.

49. Zeng, H., Lazarova, D. L., and Bordonaro, M. Mechanisms linking dietary fiber, gut microbiota and colon cancer prevention. *World J Gastrointest Oncol* 6:41–51, 2014.

50. Johnson, R. K., Appel, L. J., Brands, M., et al. Dietary sugars intake and cardiovascular health: A scientific statement from the American Heart Association on behalf of the American Heart Association Nutrition Committee of the Council on Nutrition, Physical Activity, and Metabolism and the Council on Epidemiology and Prevention. *Circulation* 120:1011–1020, 2009.

51. World Health Organization. *WHO Opens Public Consultation on Draft Sugars Guideline*. Available online at http://www.who.int/mediacentre/news/notes/2014/consultation-sugar-guideline/en. Accessed January 5, 2015.

52. Ervin, R. B., Kit, B. K., Carroll, M. D., and Ogden, C. L. Consumption of added sugar among U.S. children and adolescents, 2005–2008. *NCHS Data Brief* March(87):1–8, 2012.

53. Ervin, R. B., and Ogden, C. L. Consumption of added sugars among U.S. adults, 2005–2010. *NCHS Data Brief* May(122):1–8, 2013.

54. U.S. Department of Health and Human Services, Food and Drug Administration. *Health Claims Meeting Significant Scientific Agreement (SSA)*. Available online at http://www.fda.gov/Food/IngredientsPackagingLabeling/LabelingNutrition/ucm2006876.htm. Accessed December 10, 2014.

55. Shankar, P., Ahuja, S., and Sriram, K. Non-nutritive sweeteners: Review and update. *Nutrition* 29:1293–1299, 2013.

56. American Dietetic Association. Position of the American Dietetic Association: Use of nutritive and non-nutritive sweeteners. *J Am Diet Assoc* 112:739–758, 2012.

Chapter 5

1. U.S. Department of Agriculture, Agricultural Research Service. Table 1, nutrient intakes from food and beverages: Mean amounts consumed per individual by gender and age, in the United States, 2011–2012, *What We Eat in America* (NHANES 2011–2012). Available online at http://www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/1112/Table_1_NIN_GEN_11.pdf. Accessed December 16, 2014.

2. Popkin, B. M., Siega-Riz, A. M., Haines, P. S., and Jahns, L. Where's the fat? Trends in U.S. diets 1965–1996. *Prev Med* 32:245–254, 2001.

3. Poti, J. M., and Popkin, B. M. Trends in energy intake among US children by eating location and food source, 1977–2006. *J Am Diet Assoc* 111:1156–1164, 2011.

4. Guthrie, J. F., Lin, B. H., and Frazao, E. Role of food prepared away from home in the American diet, 1977–78 versus 1994–96: Changes and consequences. *J Nutr Educ Behav* 34:140–150, 2002.

5. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids*. Washington, DC: National Academies Press, 2002, 2005.

6. Centers for Disease Control and Prevention. Trends in intake of energy and macronutrients—United States, 1971–2000. *MMWR Morb Mortal Wkly Rep* 53:80–82, 2004.

7. U.S. Food and Drug Administration. *Final Determination Regarding Partially Hydrogenated Oils (Removing* Trans *Fat)*. Available online at http://www.fda.gov/Food/IngredientsPackagingLabeling/FoodAdditivesIngredients/ucm449162.htm. Accessed July 28, 2015.

8. Lindquist, S., and Hernell, O. Lipid digestion and absorption in early life: An update. *Curr Opin Clin Nutr Metab Care* 13:314–320, 2010.

9. Fredrickson, D. S., Goldstein, J. L., and Brown, M. S. The familial hypercholesterolemias. In *The Metabolic Basis of Inherited Disease*, 4th ed. J. B. Stanbury, J. B. Wyngaarden, and D. S. Fredrickson, Eds. New York: McGraw-Hill, 1974, pp. 604–655.

10. Goldstein, J. L., and Brown, M. S. The LDL receptor locus and the genetics of familial hypercholesterolemia. *Ann Rev Genet* 13:259–289, 1979.

11. Goldstein, J. L., and Brown, M. S. Familial hypercholesterolemia: Identification of a defect in the regulation of 3-hydroxy-3-methylglutaryl coenzyme A reductase activity associated with overproduction of cholesterol. *Proc Natl Acad Sci USA* 70:2804–2808, 1973.

12. Brown, M. S., and Goldstein, J. L. Familial hypercholesterolemia: Defective binding of lipoproteins to cultured fibroblasts associated with impaired regulation of 3-hydroxy-3-methylglutaryl coenzyme A reductase activity. *Proc Nat Acad Sci* 71:788–792, 1974.

13. Goldstein, J. L., and Brown, M. S. The LDL receptor. *Arterioscler Thromb Vasc Biol* 29:431–438, 2009.

14. Endo, A. A historical perspective on the discovery of statins. *Proc Jpn Acad Ser B Phys Biol Sci* 86:484–493, 2010.

15. Doing things differently. *Pfizer 2008 Annual Review*, April 23, 2009, p. 15.

16. Stone, N. J., Robinson, J., Lichtenstein, A. H., et al. 2013 ACC/AHA guideline on the treatment of blood cholesterol to reduce atherosclerotic cardiovascular risk in adults: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation* 129(25 Suppl 2):S1-S45, 2014.

17. Nakamura, M. T., Yudell, B. E., and Loor, J. J. Regulation of energy metabolism by long-chain fatty acids. *Prog Lipid Res* 53:124–144, 2014.

18. Kromhout, D., and de Goede, J. Update on cardiometabolic health effects of ω-3 fatty acids. *Curr Opin Lipidol*.25:85–90, 2014.

19. Wall, R., Ross, R. P., Fitzgerald, G. F., and Stanton, C. Fatty acids from fish: The anti-inflammatory potential of long-chain omega-3 fatty acids. *Nutr Rev* 68:280–289, 2010.

20. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.

21. Mozaffarian, D., Benjamin, E. J., Go, A. S., et al. Heart disease and stroke statistics—2015 update: A report from the American Heart Association. *Circulation* 131:434–441, 2015.

22. Salisbury, D., and Bronas, U. Inflammation and immune system contribution to the etiology of atherosclerosis: Mechanisms and methods of assessment. *Nurs Res* 63:375–385, 2014.

23. Choi, S. Y., and Mintz, G. S. What have we learned about plaque rupture in acute coronary syndromes? *Curr Cardiol Rep* 12:338–343, 2010.

24. Eckel, R. H., Jakicic, J. M., Ard, J. D., et al. 2013 AHA/ACC guideline on lifestyle management to reduce cardiovascular risk: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation* 129(25, suppl 2):S76–S99, 2014.

25. Bhupathiraju, S. N., and Tucker, K. L. Coronary heart disease prevention: Nutrients, foods, and dietary patterns. *Clin Chim Acta* 412:1493–1514, 2011.

26. Massaro, M., Scoditti, E., Carluccio, M. A., et al. Omega-3 fatty acids, inflammation and angiogenesis: Basic mechanisms behind the cardioprotective effects of fish and fish oils. *Cell Mol Biol* 56:59–82, 2010.

27. Sabaté, J., and Wien, M. Nuts, blood lipids and cardiovascular disease. *Asia Pac J Clin Nutr* 19:131–136, 2010.

28. Ye, E. Q., Chacko, S. A., Chou, E. L., et al. Greater whole-grain intake is associated with lower risk of type 2 diabetes, cardiovascular disease, and weight gain. *J Nutr* 142:1304–1313, 2012.

29. O'Keefe, J. H., Bhatti, S. K., Bajwa, A., et al. Alcohol and cardiovascular health: The dose makes the poison. . .or the remedy. *Mayo Clin Proc* 89:382–393, 2014.

30. Hooper, L., Kay, C., Abdelhamid, A., et al. Effects of chocolate, cocoa, and flavan-3-ols on cardiovascular health: A systematic review and meta-analysis of randomized trials. *Am J Clin Nutr* 95:740–751, 2012.

31. Nagarajan, S. Mechanisms of anti-atherosclerotic functions of soy-based diets. *J Nutr Biochem* 21:255–260, 2010.

32. Gupta, A. K., Savopoulos, C. G., Ahuja, J., and Hatzitolios, A. I. Role of phytosterols in lipid-lowering: Current perspectives. *QJM* 104:301–308, 2011.

33. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Available online at http://health.gov/dietaryguidelines/2015-scientific-report/pdfs/scientific-report-of-the-2015-dietary-guidelines-advisory-committee.pdf. Accessed January 17, 2016.

34. Fernandez, M. L., and West, K. L. Mechanisms by which dietary fatty acids modulate plasma lipids. *J Nutr* 135:2075–2078, 2005.

35. Flock, M. R., and Kris-Etherton, P. M. Diverse physiological effects of long-chain fatty acids: Implications for cardiovascular disease. *Curr Opin Clin Nutr Metab Care* 16:133–140, 2013.

36. Hunter, J. E., Zhang, J., and Kris-Etherton, P. M. Cardiovascular disease risk of dietary stearic acid compared with trans, other saturated, and unsaturated fatty acids: A systematic review. *Am J Clin Nutr* 91:46–63, 2010.

37. Bester, D., Esterhuyse, A. J., Truter, E. J., and van Rooyen, J. Cardiovascular effects of edible oils: A comparison between four popular edible oils. *Nutr Res Rev* 23:334–348, 2010.

38. Babu, A. S., Veluswamy, S. K., Arena, R., et al. Virgin coconut oil and its potential cardioprotective effects. *Postgrad Med* 126:76–83, 2014.

39. Fattore, E., Bosetti, C., Brighenti, C. F., et al. Palm oil and blood lipid–related markers of cardiovascular disease: A systematic review and meta-analysis of dietary intervention trials. *Am J Clin Nutr* 99:1331–1350, 2014.

40. Mensink, R. P., Zock, P. L., Kester, A. D., and Katan, M. B. Effects of dietary fatty acids and carbohydrates on the ratio of serum total to HDL cholesterol and on serum lipids and apolipoproteins: A meta-analysis of 60 controlled trials. *Am J Clin Nutr* 77:1146–1155, 2003.

41. Feranil, A. B., Duazo, P. L., Kuzawa, C. W., and Adair, L. S. Coconut oil is associated with a beneficial lipid profile in pre-menopausal women in the Philippines. *Asia Pac J Clin Nutr* 20:190–195, 2011.

42. Assunção, M. L., Ferreira, H. S., dos Santos, A. F., et al. Effects of dietary coconut oil on the biochemical and anthropometric profiles of women presenting abdominal obesity. *Lipids* 44:593–601, 2009.

43. Voon, P. T., Ng, T. K., Lee, V. K., and Nesaretnam, K. Diets high in palmitic acid (16:0), lauric and myristic acids (12:0 + 14:0), or oleic acid (18:1) do not alter postprandial or fasting plasma homocysteine and inflammatory markers in healthy Malaysian adults. *Am J Clin Nutr* 94:1451–1457, 2011.

44. Han, J., Deng, B., Sun, J., et al. Effects of dietary medium-chain triglyceride on weight loss and insulin sensitivity in a group of moderately overweight free-living type 2 diabetic Chinese subjects. *Metabolism* 56:985–991, 2007.

45. St-Onge, M. P., and Bosarge, A. Weight-loss diet that includes consumption of medium-chain triacylglycerol oil leads to a

greater rate of weight and fat mass loss than does olive oil. *Am J Clin Nutr* 87:621–626, 2008.

46. St-Onge, M. P., Mayrsohn, B., O'Keeffe, M., et al. Impact of medium and long chain triglycerides consumption on appetite and food intake in overweight men. *Eur J Clin Nutr* 68:1134–1140, 2014.

47. Nestel, P. Trans fatty acids: Are its cardiovascular risks fully appreciated? *Clin Ther* 36:315–321, 2014.

48. Mozaffarian, D., Katan, M. B., Ascherio, A, et al. Trans fatty acids and cardiovascular disease. *N Engl J Med* 354:1601–1613, 2006.

49. Farvid, M. S., Ding, M., Pan, A., et al. Dietary linoleic acid and risk of coronary heart disease: A systematic review and meta-analysis of prospective cohort studies. *Circulation* 130:1568–1578, 2014.

50. Ooi, E. M., Ng, T. W., Watts, G. F., and Barrett, P. H. Dietary fatty acids and lipoprotein metabolism: New insights and updates. *Curr Opin Lipidol* 24:192–197, 2013.

51. Chateau-Degat, M. L., Dewailly, E., Louchini, R., et al. Cardiovascular burden and related risk factors among Nunavik (Quebec) Inuit: Insights from baseline findings in the circumpolar Inuit health in transition cohort study. *Can J Cardiol* 26:190–196, 2010.

52. American Heart Association. *Fish and Omega-3 Fatty Acids*. Available online at http://www.heart.org/HEARTORG/GettingHealthy/NutritionCenter/HealthyDietGoals/Fish-and-Omega-3-Fatty-Acids_UCM_303248_Article.jsp#. Accessed December 22, 2014.

53. Jones, J. L., Comperatore, M., Barona, J., et al. A Mediterranean-style, low-glycemic-load diet decreases atherogenic lipoproteins and reduces lipoprotein (a) and oxidized low-density lipoprotein in women with metabolic syndrome. *Metabolism* 61:366–372, 2012.

54. Schwingshackl, L., and Hoffmann, G. Monounsaturated fatty acids, olive oil and health status: A systemic review and meta-analysis of cohort studies. *Lipids Health Dis* 13:154–169, 2014.

55. Willett, W. C., Sacks, F., Trichopouluo, A., et al. Mediterranean diet pyramid: A cultural model for healthy eating. *Am J Clin Nutr* 61(suppl):1402S–1406S, 1995.

56. Stradling, C., Hamid, M., Taheri, S., and Thomas, G. N. A review of dietary influences on cardiovascular health: Part 2: Dietary patterns. *Cardiovasc Hematol Disord Drug Targets* 14:50–63, 2014.

57. Zhang, P. Y., Xu, X., and Li, X. C. Cardiovascular diseases: Oxidative damage and antioxidant protection. *Eur Rev Med Pharmacol Sci* 18:3091–3096, 2014.

58. Debreceni, B., and Debreceni, L. The role of homocysteine-lowering B-vitamins in the primary prevention of cardiovascular disease. *Cardiovasc Ther* 32:130–138, 2014.

59. Yang, Q., Botto, L. D., Erickson, J. D., et al. Improvement in stroke mortality in Canada and the United States, 1990 to 2002. *Circulation* 113:1335–1343, 2006.

60. American Heart Association. *Homocysteine, Folic Acid and Cardiovascular Disease.* Available online at http://www.heart.org/HEARTORG/GettingHealthy/NutritionCenter/Homocysteine-Folic-Acid-and-Cardiovascular-Disease_UCM_305997_Article.jsp. Accessed January 27, 2015.

61. Klatsky, A. L. Alcohol and cardiovascular health. *Physiol Behav* 100:76–81, 2010.

62. World Cancer Research Fund/American Institute for Cancer Research (AICR). *Food, Nutrition, Physical Activity, and Prevention of Cancer: A Global Perspective* Washington, DC: AICR, 2007.

63. Abel, S., Riedel, S., and Gelderblom, W. C. Dietary PUFA and cancer. *Proc Nutr Soc* 73:361–367, 2014.

64. Schwingshackl, L., and Hoffmann, G. Adherence to Mediterranean diet and risk of cancer: A systematic review and meta-analysis of observational studies. *Int J Cancer* 135:1884–1897, 2014.

65. Albuquerque, R. C., Baltar, V. T., and Marchioni, D. M. Breast cancer and dietary patterns: A systematic review. *Nutr Rev* 72:1–17, 2014.

66. Makarem, N., Chandran, U., Bandera, E. V., and Parekh, N. Dietary fat in breast cancer survival. *Annu Rev Nutr* 33:319–348, 2013.

67. Devitt, A. A., and Mattes, R. D. Effects of food unit size and energy density on intake in humans. *Appetite* 42: 213–220, 2004.

68. Ledikwe, J. H., Blanck, H. M., Kettel Khan, L., et al. Dietary energy density is associated with energy intake and weight status in US adults. *Am J Clin Nutr* 83:1362–1368, 2006.

69. Donahoo, W., Wyatt, H. R., Kriehn, J., et al. Dietary fat increases energy intake across the range of typical consumption in the United States. *Obesity (Silver Spring)* 16:64–69, 2008.

70. Melanson, E. L., Astrup, A., and Donahoo, W. T. The relationship between dietary fat and fatty acid intake and body weight, diabetes, and the metabolic syndrome. *Ann Nutr Metab* 55:229–243, 2009.

71. Rong, Y., Chen, L., Zhu, T., et al. Egg consumption and risk of coronary heart disease and stroke: Dose-response meta-analysis of prospective cohort studies. *BMJ* 346:e8539, 2013.

72. Katz, D. L., Gnanaraj, J., Treu, J. A., et al. Effects of egg ingestion on endothelial function in adults with coronary artery disease: A randomized, controlled, crossover trial. *Am Heart J* 169:162–169, 2015.

73. Nutrition labeling of single-ingredient products and ground or chopped meat and poultry products; final rule. *Federal Register* 75(249):82148–82167, December 29, 2010.

74. Remig, V., Franklin, B., Margolis, S., et al. Trans fats in America: A review of their use, consumption, health implications, and regulation. *J Am Diet Assoc* 110:585–592, 2010.

75 American Heart Association Nutrition Committee, Lichtenstein, A. H., Appel, L. J., Brands, M., et al. Diet and lifestyle recommendations revision 2006: A scientific statement from the American Heart Association Nutrition Committee. *Circulation* 114:82–96, 2006.

76. American Dietetic Association. Position of the American Dietetic Association: Fat replacers. *J Am Diet Assoc* 105:266–275, 2005.

FOCUS ON Alcohol

1. Elamin, E. E., Masclee, A. A., Dekker, J., and Jonkers, D. M. Ethanol metabolism and its effects on the intestinal epithelial barrier. *Nutr Rev* 71:483–499, 2013.
2. Baraona, E., Abittan, C. S., Dohmen, K., et al. Gender differences in pharmacokinetics of alcohol. *Alcohol Clin Exp Res* 25:502–507, 2001.
3. Centers for Disease Control and Prevention. *FastStats: Alcohol Use*. Available online at http://www.cdc.gov/nchs/fastats/alcohol.htm. Accessed January 24, 2015.
4. Silveri, M. M. Adolescent brain development and underage drinking in the United States: Identifying risks of alcohol use in college populations. *Harv Rev Psychiatry* 20:189–200, 2012.
5. U.S. Department of Transportation. *Traffic Safety Facts 2012*. Available online at http://www-nrd.nhtsa.dot.gov/Pubs/812032.pdf. Accessed January 23, 2015.
6. Centers for Disease Control and Prevention. *FastStats: Underage Drinking*. Available online at http://www.cdc.gov/alcohol/fact-sheets/underage-drinking.htm. Accessed February 4, 2015.
7. National Institute on Alcohol Abuse and Alcoholism. *College Drinking*. Available online at http://www.niaaa.nih.gov/alcohol-health/special-populations-co-occurring-disorders/college-drinking. Accessed January 23, 2015.
8. Arria, A. M., and O'Brien, M. C. The "high" risk of energy drinks. *JAMA* 305:600–601, 2011.
9. Centers for Disease Control and Prevention. *Fact Sheets—Caffeine and Alcohol*. Available online at http://www.cdc.gov/alcohol/fact-sheets/caffeine-and-alcohol.htm. Accessed April 9, 2015.
10. Lucas, D. L., Brown, R. A., Wassef, M., and Giles, T. D. Alcohol and the cardiovascular system: Research challenges and opportunities. *J Am Coll Cardiol* 45:1916–1924, 2005.
11. Testino, G. The burden of cancer attributable to alcohol consumption. *Maedica (Buchar)* 6:313–320, 2011.
12. Lieber, C. S. Relationships between nutrition, alcohol use, and liver disease. *Alcohol Res Health* 27:220–231, 2003.
13. Sayon-Orea, C., Martinez-Gonzalez, M. A., and Bes-Rastrollo, M. Alcohol consumption and body weight: A systematic review. *Nutr Rev* 69:419–431, 2011.
14. Bendsen, N. T., Christensen, R., Bartels, E. M., et al. Is beer consumption related to measures of abdominal and general obesity? A systematic review and meta-analysis. *Nutr Rev* 71:67–87, 2013.
15. McClain, C. J., Barve, S. S., Barve, A., and Marsano, L. Alcoholic liver disease and malnutrition. *Alcohol Clin Exp Res* 35:815–820, 2011.
16. Ceni, E., Mello, T., and Gilli, A. Pathogenesis of alcoholic liver disease: Role of oxidative metabolism. *World J Gastroenterol* 20:17756–17772, 2014.
17. de Menezes, R. F., Bergmann, A., and Thuler, L. C. Alcohol consumption and risk of cancer: A systematic literature review. *Asian Pac J Cancer Prev* 14:4965–4972, 2013.
18. Castro, G. D., and Castro, J. A. Alcohol drinking and mammary cancer: Pathogenesis and potential dietary preventive alternatives. *World J Clin Oncol* 5:713–729, 2014.
19. World Cancer Research Fund/American Institute for Cancer Research (AICR). *Food, Nutrition, Physical Activity, and Prevention of Cancer: A Global Perspective*. Washington, DC: AICR, 2010.
20. Varela-Rey, M., Woodhoo, A., Martinez-Chantar, M. L., et al. Alcohol, DNA methylation, and cancer. *Alcohol Res* 35:25–35, 2013.
21. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*, 5th ed. Arlington, VA: American Psychiatric Publishing, 2013.
22. National Institute on Alcohol Abuse and Alcoholism. *Alcohol Use Disorder*. Available online at http://www.niaaa.nih.gov/alcohol-health/overview-alcohol-consumption/alcohol-use-disorders. Accessed January 23, 2015.
23. Samochowiec, J., Samochowiec, A., Puls, I., et al. Genetics of alcohol dependence: A review of clinical studies. *Neuropsychobiology* 70:77–94, 2014.
24. O'Keefe, J. H., Bhatti, S. K., Bajwa, A., et al. Alcohol and cardiovascular health: The dose makes the poison…or the remedy. *Mayo Clin Proc* 89:382–393, 2014.
25. Saremi, A., and Arora, R. The cardiovascular implications of alcohol and red wine. *Am J Ther* 15:265–277, 2008.
26. Goldfinger, T. M. Beyond the French paradox: The impact of moderate beverage alcohol and wine consumption in the prevention of cardiovascular disease. *Cardiol Clin* 21:449–457, 2003.
27. Di Castelnuovo, A., Costanzo, S., Bagnardi, V., et al. Alcohol dosing and total mortality in men and women; an update meta-analysis of 34 prospective studies. *Arch Intern Med* 166:2437–2445, 2006.
28. Klatsky, A. L. Alcohol and cardiovascular diseases. *Expert Rev Cardiovasc Ther* 7:499–506, 2009.
29. Nova, E., Baccan, G. C., Veses, A., et al. Potential health benefits of moderate alcohol consumption: Current perspectives in research. *Proc Nutr Soc* 71:307–315, 2012.
30. American Heart Association. *Alcohol and Heart Health*. Available online at http://www.heart.org/HEARTORG/Conditions/More/MyHeartandStrokeNews/Alcohol-and-Heart-Disease_UCM_305173_Article.jsp. Accessed January 24, 2015.
31. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.

Chapter 6

1. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.
2. U.S. Department of Agriculture, Agricultural Research Service. Table 5: Energy intakes: Percentages of energy from protein, carbohydrate, fat, and alcohol, by gender and age in the United States, 2011–2012. *What We Eat in America* (NHANES 2011–2012). Available online at http://www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/1112/Table_5_EIN_GEN_11.pdf. Accessed April 11, 2015.

3. O'Neil, C. E., Keast, D. R., Fulgoni, V. L., & Nicklas, T. A. Food sources of energy and nutrients among adults in the US: NHANES 2003–2006. *Nutrients*, 4:2097–2120, 2012.

4. Roberts, R. J. How restriction enzymes became the workhorses of molecular biology. *Proc Natl Acad Sci USA* 102:5905–5908, 2005.

5. Meselson, M., and Yuan, R. DNA restriction enzyme from *E. coli*. *Nature* 217:1110–1114, 1968.

6. Smith, H. O., and Wilcox, K. W. A restriction enzyme from *Hemophilus influenzae*. I. Purification and general properties. *J Mol Biol* 51:379–391, 1970.

7. Arber, W. Host-controlled modification of bacteriophage. *Annu Rev Microbiol* 19:365–378, 1965.

8. Danna, K., and Nathans, D. Specific cleavage of simian virus 40 DNA by restriction endonuclease of *Hemophilus influenzae*. *Proc Natl Acad Sci USA* 68:2913–2917, 1971.

9. WHO/UNICEF/SCN/WFP Joint Statement, 2007. *Community-Based Management of Severe Acute Malnutrition*. Available online at http://www.unicef.org/publications/files/Community_Based_Management_of_Sever_Acute__Malnutirtion.pdf. Accessed January 2, 2015.

10. Williams, C. D. Kwashiorkor: Nutritional disease of children associated with maize diet. *Lancet* 2:1151–1154, 1935.

11. Garrett, W. S. Kwashiorkor and the gut microbiota. *N Engl J Med* 368:1746–1747, 2013.

12. Pesta, D. H., and Samuel, V. T. A high-protein diet for reducing body fat: Mechanisms and possible caveats. *Nutr Metab (Lond)* 11:53, 2014.

13. Martens, E. A., Gonnissen, H. K., Gatta-Cherifi, B., et al. Maintenance of energy expenditure on high-protein vs. high-carbohydrate diets at a constant body weight may prevent a positive energy balance. *Clin Nutr* 34:968–975, 2015.

14. Matarese, L. E., and Pories, W. J. Adult weight loss diets: Metabolic effects and outcomes. *Nutr Clin Pract* 29:759–767, 2014.

15. Soenen, S., Bonomi, A. G., Lemmens, S. G., et al. Relatively high-protein or "low-carb" energy-restricted diets for body weight loss and body weight maintenance? *Physiol Behav* 107:374–380, 2012.

16. Neacsu, M., Fyfe, C., Horgan, G., and Johnstone, A. M. Appetite control and biomarkers of satiety with vegetarian (soy) and meat-based high-protein diets for weight loss in obese men: A randomized crossover trial. *Am J Clin Nutr* 100:548–558, 2014.

17. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Available online at http://health.gov/dietaryguidelines/2015-scientific-report/pdfs/scientific-report-of-the-2015-dietary-guidelines-advisory-committee.pdf. Accessed January 17, 2016.

18. Santesso, N., Akl, E. A., Bianchi, M., et al. Effects of higher- versus lower-protein diets on health outcomes: A systematic review and meta-analysis. *Eur J Clin Nutr* 66:780–788, 2012.

19. Schwingshackl, L., and Hoffmann, G. Long-term effects of low-fat diets either low or high in protein on cardiovascular and metabolic risk factors: A systematic review and meta-analysis. *Nutr J* 12:48, 2013.

20. Lagiou, P., Sandin, S., Lof, M., et al. Low carbohydrate-high protein diet and incidence of cardiovascular diseases in Swedish women: Prospective cohort study. *BMJ* 344:e4026, 2012.

21. Noto, H., Goto, A., Tsujimoto, T., and Noda, M. Low-carbohydrate diets and all-cause mortality: A systematic review and meta-analysis of observational studies. *PLoS One* 8:e55030, 2013.

22. Bernstein, A. M., Sun, Q., Hu, F. B., et al. Major dietary protein sources and risk of coronary heart disease in women. *Circulation* 122:876–883, 2010.

23. Ferguson, L. R. Meat and cancer. *Meat Sci* 84:308–313, 2010.

24. Levine, M. E., Suarez, J. A., Brandhorst, S., et al. Low protein intake is associated with a major reduction in IGF-1, cancer, and overall mortality in the 65 and younger but not older population. *Cell Metab* 19:407–417, 2014.

25. Marckmann, P., Osther, P., Pedersen, A. N., and Jespersen, B. High-protein diets and renal health. *J Ren Nutr* 25:1–5, 2015.

26. Juraschek, S. P., Appel, L. J., Anderson, C. A., and Miller, E. R., 3rd. Effect of a high-protein diet on kidney function in healthy adults: Results from the OmniHeart trial. *Am J Kidney Dis* 61:547–554, 2013.

27. Heaney, R. P., and Layman, D. K. Amount and type of protein influences bone health. *Am J Clin Nutr* 87:1567S–1570S, 2008.

28. Tang, M., O'Connor, L. E., and Campbell, W. W. Diet-induced weight loss: The effect of dietary protein on bone. *J Acad Nutr Diet* 114:72–85, 2014.

29. Remer, T., Krupp, D., and Shi, L. Dietary protein's and dietary acid load's influence on bone health. *Crit Rev Food Sci Nutr* 54:1140–1150, 2014.

30. Mangano, K. M., Sahni, S., and Kerstetter, J. E. Dietary protein is beneficial to bone health under conditions of adequate calcium intake: An update on clinical research. *Curr Opin Clin Nutr Metab Care* 17:69–74, 2014.

31. Meschi, T., Nouvenne, A., and Borghi, L. Lifestyle recommendations to reduce the risk of kidney stones. *Urol Clin North Am* 38:313–320, 2011.

32. Randi, G., Edefonti, V., Ferraroni, M., et al. Dietary patterns and the risk of colorectal cancer and adenomas. *Nutr Rev* 68:389–408, 2010.

33. Kim, E., Coelho, D., and Blachier, F. Review of the association between meat consumption and risk of colorectal cancer. *Nutr Res* 33:983–994, 2013.

34. U.S. Food and Drug Administration *Food Allergen Labeling and Consumer Protection Act of 2004*. Available online at http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/Allergens/ucm106187.htm. Accessed June 13, 2015.

35. Catassi, C., Bai, J. C., Bonaz, B., et al. Non-celiac gluten sensitivity: The new frontier of gluten related disorders. *Nutrients* 5:3839–3853, 2013.

36. Rubio-Tapia, A., Ludvigsson, J. F., Brantner, T. L., et al. The prevalence of celiac disease in the United States. *Am J Gastroenterol* 107:1538–1545, 2012.

37. Williams, R. A., Mamotte, C. D., and Burnett, J. R. Phenylketonuria: An inborn error of phenylalanine metabolism. *Clin Biochem Rev* 29:31–41, 2008.

38. Camp, K. M., Parisi, M. A., Acosta, P. B., et al. Phenylketonuria Scientific Review Conference: State of the science and future research needs. *Mol Genet Metab* 112:87–122, 2014.

39. Williams, A. N., and Woessner, K. M. Monosodium glutamate "allergy": Menace or myth? *Clin Exp Allergy* 39:640–646, 2009.

40. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids.* Washington, DC: National Academies Press, 2002, 2005.

41. Bauer, J., Biolo, G., Cederholm, T., et al. Evidence-based recommendations for optimal dietary protein intake in older people: A position paper from the PROT-AGE Study Group. *J Am Med Dir Assoc* 14:542–559, 2013.

42. American Dietetic Association. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *J Am Diet Assoc* 109:509–527, 2009.

43. Zajac, A., Poprzecki, S., Zebrowska, A., et al. Arginine and ornithine supplementation increases growth hormone and insulin-like growth factor-1 serum levels after heavy-resistance exercise in strength-trained athletes. *J Strength Cond Res* 24:1082–1090, 2010.

44. Lavesque, C. L., and Ball, R. O. Protein and amino acid requirements. In *Biochemical, Physiological and Molecular Aspects of Human Nutrition*, 3rd ed. M. H. Stipanik and M. A. Caudill, Eds. St. Louis, MO: Saunders Elsevier, 2013, pp. 331–356.

45. Boye, J., Wijesinha-Bettoni, R., and Burlingame, B. Protein quality evaluation twenty years after the introduction of the protein digestibility corrected amino acid score method. *Br J Nutr* 108(suppl 2):S183–S211, 2012.

46. Leser, S. The 2013 FAO report on dietary protein quality evaluation in human nutrition: Recommendations and implications. *Nutr Bull* 38:421–428, 2013.

47. Food and Agriculture Organization/World Health Organization. *Protein Quality Evaluation. Report of the Joint FAO/WHO Expert Consultation*. Rome: FAO/WHO, 1989.

48. Le, L. T., and Sabaté, J. Beyond meatless, the health effects of vegan diets: Findings from the Adventist cohorts. *Nutrients* 6:2131–2147, 2014.

49. Craig, W. J., Mangels, A.R.; American Dietetic Association. Position of the American Dietetic Association: Vegetarian diets. *J Am Diet Assoc* 109:1266–1282, 2009.

Chapter 7

1. Ogden, C. L., Carroll, M. D., Kit, B. K., and Flegal, K. M. Prevalence of childhood and adult obesity in the United States, 2011– 2012. *JAMA* 311:806–814, 2014.

2. World Health Organization. *Obesity and Overweight*. Available online at http://www.who.int/mediacentre/factsheets/fs311/en. Accessed April 12, 2015.

3. Wiederman, A. J. The high (and mostly hidden) costs of obesity. *Daily Finance*, September 25, 2015. Available online at http://www.dailyfinance.com/2013/09/25/obesity-high-mostly-hidden-costs. Accessed April 13, 2015.

4. Centers for Disease Control and Prevention. *Obesity Prevalence Maps. Prevalence of Self-Reported Obesity among U.S. Adults by State and Territory, BRFSS, 2013*. Behavioral Risk Factor Surveillance Systems. Available online at http://www.cdc.gov/obesity/data/prevalence-maps.html. Accessed February 7, 2015.

5. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Available online at http://health.gov/dietaryguidelines/2015-scientific-report/pdfs/scientific-report-of-the-2015-dietary-guidelines-advisory-committee.pdf. Accessed January 17, 2016.

6. Shah, T., Purohit, G., Nair, S. P., et al. Assessment of obesity, overweight and its association with the fast food consumption in medical students. *J Clin Diagn Res* 8:CC05–CC07, 2014.

7. Flint, E., Cummins, S., and Sacker, A. Associations between active commuting, body fat, and body mass index: Population based, cross sectional study in the United Kingdom. *BMJ* 349:g4887, 2014.

8. Borrell, L. N., and Samuel, L. Body mass index categories and mortality risk in US adults: The effect of overweight and obesity on advancing death. *Am J Public Health* 104:512–519, 2014.

9. Centers for Disease Control and Prevention. *Healthy Weight—It's Not a Diet, It's a Lifestyle!* Available online at http://www.cdc.gov/healthyweight/losing_weight/index.html?s_cid5govD_dnpao_082. Accessed February 3, 2015.

10. Bonfrate, L., Wang, D. Q., Garruti, G., and Portincasa, P. Obesity and the risk and prognosis of gallstone disease and pancreatitis. *Best Pract Res Clin Gastroenterol* 28:623–635, 2014.

11. Jordan, A. S., McSharry, D. G., and Malhotra, A. Adult obstructive sleep apnoea. *Lancet* 383:736–747, 2014.

12. National Heart, Lung, and Blood Institute, National Institutes of Health. *How Is Sleep Apnea Treated?* Available online at http://www.nhlbi.nih.gov/health/health-topics/topics/sleepapnea/treatment. Accessed February 5, 2015.

13. National Cancer Institute. *Obesity and Cancer Risk*. Available online at http://www.cancer.gov/cancertopics/factsheet/Risk/obesity. Accessed January 3, 2015.

14. Endogenous Hormones and Breast Cancer Collaborative Group, Key, T. J., Appleby, P. N., et al. Circulating sex hormones and breast cancer risk factors in postmenopausal women: Reanalysis of 13 studies. *Br J Cancer* 105:709–722, 2011.

15. Thijssen, E., van Caam, A., and van der Kraan, P. M. Obesity and osteoarthritis, more than just wear and tear: Pivotal roles for inflamed adipose tissue and dyslipidaemia in obesity-induced osteoarthritis. *Rheumatology (Oxford)* 54:588–600, 2015.

16. Lementowski, P. W., and Zelicof, S. B. Obesity and osteoarthritis. *Am J Orthop* 37:148–151, 2008.

17. Gunnarsdottir, T., Njardvik, U., Olafsdottir, A. S., et al. Teasing and social rejection among obese children enrolling in family-based behavioural treatment: Effects on psychological adjustment and academic competencies. *Int J Obes (Lond)* 36:35–44, 2012.

18. Vander Wal, J. S., and Mitchell, E. R. Psychological complications of pediatric obesity. *Pediatr Clin North Am* 58:1393–1401, 2011.

19. Faith, M. S., Butryn, M., Wadden, T. A., et al. Evidence for prospective associations among depression and obesity in population-based studies. *Obes Rev* 12:e438–e453, 2011.

20. Flegal, K. M., Graubard, B. I., Williamson, D. F., and Gail, M. H. Cause-specific deaths associated with underweight, overweight, and obesity. *JAMA* 298:2028–2037, 2007.

21. National Heart, Lung, and Blood Institute, National Institutes of Health. *The Practical Guide: Identification, Evaluation and Treatment of Overweight and Obesity in Adults* (NIH Publication no. 02-4084). Bethesda, MD: National Institutes of Health, 2002.

22. Goyal, A., Nimmakayala, K. R., and Zonszein, J. Is there a paradox in obesity? *Cardiol Rev* 22:163–170, 2014.

23. Barry, V. W., Baruth, M., Beets, M. W., et al. Fitness vs. fatness on all-cause mortality: A meta-analysis. *Prog Cardiovasc Dis* 56:382–390, 2014.

24. Gallagher, D., Heymsfield, S., Heo, M., et al. Healthy percentage body fat ranges: An approach for developing guidelines based on body mass index. *Am J Clin Nutr* 72:694–701, 2000.

25. Evans, W. J. Protein nutrition, exercise and aging. *J Am Coll Nutr* 23:601S–609S, 2004.

26. Tucker, L. A., Lecheminant, J. D., and Bailey, B. W. Test–retest reliability of the Bod Pod: The effect of multiple assessments. *Percept Mot Skills* 118:563–570, 2014.

27. Petak, S., Barbu, C. G., Yu, E. W., et al. The official positions of the International Society for Clinical Densitometry: Body composition analysis reporting. *J Clin Densitom* 16:508–519, 2013.

28. Alexopoulos, N., Katritsis, D., and Raggi, P. Visceral adipose tissue as a source of inflammation and promoter of atherosclerosis. *Atherosclerosis* 233:104–112, 2014.

29. Tchernof, A., and Després, J. P. Pathophysiology of human visceral obesity: An update. *Physiol Rev* 93:359–404, 2013.

30. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Protein and Amino Acids*. Washington, DC: National Academies Press, 2002/2005.

31. Maclean, P. S., Bergouignan, A., Cornier, M. A., and Jackman, M. R. Biology's response to dieting: The impetus for weight regain. *Am J Physiol Regul Integr Comp Physiol* 301: R581–R600, 2011.

32. Ochner, C. N., Barrios, D. M., Lee, C. D., and Pi-Sunyer, F. X. Biological mechanisms that promote weight regain following weight loss in obese humans. *Physiol Behav* 120:106–113, 2013.

33. Kriketos, A. D., Peters, J. C., and Hill, J. O. Cellular and whole-animal energetics. In *Biochemical and Physiological Aspects of Human Nutrition*. M. H. Stipanuk, Ed. Philadelphia: W. B. Saunders, 2000, pp. 411–424.

34. Pereira-Lancha, L. O., Coelho, D. F., de Campos-Ferraz, P. L., and Lancha, Jr., A. H. Body fat regulation: Is it a result of a simple energy balance or a high fat intake? *J Am Coll Nutr* 29:343–351, 2010.

35. Cahill, G. F., Starvation in man. *N Engl J Med* 282:668–675, 1970.

36. Frayn, K. *Metabolic Regulation: A Human Perspective*. London: Portland Press, 1996, pp. 78–102.

37. Bouchard, C. Genetics of human obesity: Recent results from linkage studies. *J Nutr* 127:1887S–1890S, 1997.

38. Bouchard, C., Tremblay, A., Després, J.-P., et al. The response to long term feeding in identical twins. *N Engl J Med* 322:1477–1482, 1990.

39. Waalen, J. The genetics of human obesity. *Transl Res* 164:293–301, 2014.

40. Ravussin, E., Valencia, M. E., Esparza, J., et al. Effects of a traditional lifestyle on obesity in Pima Indians. *Diabetes Care* 17:1067–1074, 1994.

41. Norman, R. A., Thompson, D. B., Foroud, T., et al. Genomewide search for genes influencing percent body fat in Pima Indians: Suggestive linkage at chromosome 11q21–q22. *Am J Hum Genet* 60:166–173, 1997.

42. Esparza, J., Fox, C., Harper, I. T., et al. Daily energy expenditure in Mexican and USA Pima Indians: Low physical activity as a possible cause of obesity. *Int J Obes Relat Metab Disord* 24:55–59, 2000.

43. Berryman, D. E., Davy, B. M., and List, E. O. Control of energy balance. In *Biochemical, Physiological, and Molecular Aspects of Human Nutrition*, 3rd ed. M. H. Stipanuk and M. A. Caudill, Eds. Philadelphia: W. B. Saunders, 2013, pp. 501–518.

44. Hussain, S. S., De Silva, A., and Bloom, S. R. Controls of food intake and appetite. In *Modern Nutrition in Health and Disease*, 11th ed. A. C. Ross, B. Caballero, R. J. Cousins, et al., Eds. Philadelphia: Lippincott Williams & Wilkins, 2014, pp. 589–600.

45. Adams, C. E., Greenway, F. L., and Brantley, P. J. Lifestyle factors and ghrelin: Critical review and implications for weight loss maintenance. *Obes Rev* 12:e211–e218, 2011.

46. Price, S. L., and Bloom, S. R. Protein PYY and its role in metabolism. *Front Horm Res* 42:147–154, 2014.

47. Sáinz, N., Barrenetxe, J., Moreno-Aliaga, M. J., and Martínez, J. A. Leptin resistance and diet-induced obesity: Central and peripheral actions of leptin. *Metabolism* 64:35–46, 2015.

48. Farooqi, I. S., and O'Rahilly, S. 20 years of leptin: Human disorders of leptin action. *J Endocrinol* 223:T63–T70, 2014.

49. Tremblay, A., Després, J.-P., Thriault, G., et al. Overfeeding and energy expenditure in humans. *Am J Clin Nutr* 56:857–862, 1992.

50. Diaz, E. O., Prentice, A. M., Goldberg, G. R., et al. Metabolic response to experimental overfeeding in lean and overweight healthy volunteers. *Am J Clin Nutr* 56:641–655, 1992.

51. Zhang, Y., Proenca, R., Maffei, M., et al. Positional cloning of the mouse obese gene and its human homologue. *Nature* 372:425–432, 1994.

52. Halaas, J. L., Gajiwala, K. S., Maffei, M., et al. Weight-reducing effects of the plasma protein encoded by the obese gene. *Science* 269:543–546, 1995.

53. Pelleymounter, M. A., Cullen, M. J., Baker, M. B., et al. Effects of the obese gene product on body weight regulation in ob/ob mice. *Science* 269:540–543, 1995.

54. Montague, C. T., Farooqi, I. S., Whitehead, J. P., et al. Congenital leptin deficiency is associated with severe early onset obesity in children. *Nature* 387:903–908, 1997.

55. Considine, R. V., Sinha, M. K., Heiman, M. L., et al. Serum immunoreactive-leptin concentrations in normal weight and obese humans. *N Engl J Med* 334:292–295, 1996.

56. Gura, T. Obesity research: Leptin not impressive in clinical trial. *Science* 286:881–882, 1999.

57. Tartaglia, L. A., Dembski, M., Weng X., et al. Identification and expression cloning of a leptin receptor, *OB-R*. Cell 83:1263–1271, 1995.

58. Tsigos, C., Kyrou, I., and Raptis, S. A. Monogenic forms of obesity and diabetes mellitus. *J Pediatr Endocrinol Metab* 15:241–253, 2002.

59. Gura, T. Tracing leptin's partners in regulating body weight. *Science* 287:1738–1741, 2000.

60. Lee, Y. H., Jung, Y. S., and Choi, D. Recent advance in brown adipose physiology and its therapeutic potential. *Exp Mol Med*. 46:e78, 2014.

61. van Marken Lichtenbelt, W. D., Vanhommerig, J. W., Smulders, N. M., et al. Cold-activated brown adipose tissue in healthy men. *N Engl J Med* 360:1500–1508, 2009.

62. Levine, J. A. Nonexercise activity thermogenesis—Liberating the life-force. *J Intern Med*. 262:273–287, 2007.

63. Levine, J. A., Eberhardt, N. L., and Jensen, M. D. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. *Science* 283:212–214, 1999.

64. Jensen, M. D., Ryan, D. H., Apovian, C. M., et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults. *J Am Coll Cardiol* 63:2985–3023, 2014.

65. Woo, J. Obesity in older persons. *Curr Opin Clin Nutr Metab Care* 18:5–10, 2015.

66. Waters, D. L., Ward, A. L., and Villareal, D. T. Weight loss in obese adults 65 years and older: A review of the controversy. *Exp Gerontol*. 48:1054–1061, 2013.

67. Valencia, W. M., Stoutenberg, M., and Florez, H. Weight loss and physical activity for disease prevention in obese older adults: An important role for lifestyle management. *Curr Diab Rep*. 14:539, 2014.

68. Santarpia, L., Contaldo, F., and Pasanisi, F. Body composition changes after weight-loss interventions for overweight and obesity. *Clin Nutr* 32:157–161, 2013.

69. U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans.* Available online at http://www.health.gov/paguidelines/guidelines. Accessed April 10, 2015.

70. National Weight Control Registry. *NWCR Facts*. Available online at http://www.nwcr.ws/research. Accessed January 8, 2015.

71. Office of the Surgeon General. *The Surgeon General's Call to Action to Prevent and Decrease Overweight and Obesity*. Rockville, MD: U.S. Department of Health and Human Services, 2001.

72. Hills, A. P., Byrne, N. M., Lindstrom, R., and Hill, J. O. "Small changes" to diet and physical activity behaviors for weight management. *Obes Facts* 6:228–238, 2013.

73. American Dietetic Association. Position of the American Dietetic Association: Weight management. *J Am Diet Assoc* 109:330–346, 2009.

74. Westman, E. C., Feinman, R. D., Mavropoulos, J. C., et al. Low-carbohydrate nutrition and metabolism. *Am J Clin Nutr* 86:276–284, 2007.

75. Hu, T., and Bazzano, L. A. The low-carbohydrate diet and cardiovascular risk factors: Evidence from epidemiologic studies. *Nutr Metab Cardiovasc Dis* 24:337–343, 2014.

76. Brinkworth, G. D., Noakes, M., Buckley, J. D., et al. Long-term effects of a very-low-carbohydrate weight loss diet compared with an isocaloric low-fat diet after 12 mo. *Am J Clin Nutr* 90:23–32, 2009.

77. Levine, M. E., Suarez, J. A., Brandhorst, S., et al. Low protein intake is associated with a major reduction in IGF-1, cancer, and overall mortality in the 65 and younger but not older population. *Cell Metab* 19:407–417, 2014.

78. Russell, W. R., Gratz, S. W., Duncan, S. H., et al. High-protein, reduced-carbohydrate weight-loss diets promote metabolite profiles likely to be detrimental to colonic health. *Am J Clin Nutr* 93:1062–1072, 2011.

79. Martens, E. A., Gonnissen, H. K., Gatta-Cherifi, B., et al. Maintenance of energy expenditure on high-protein vs. high-carbohydrate diets at a constant body weight may prevent a positive energy balance. *Clin Nutr* 34:968–975, 2015.

80. Matarese, L. E., and Pories, W. J. Adult weight loss diets: Metabolic effects and outcomes. *Nutr Clin Pract* 29:759–767, 2014.

81. Schwingshackl, L., and Hoffmann, G. Long-term effects of low-fat diets either low or high in protein on cardiovascular and metabolic risk factors: A systematic review and meta-analysis. *Nutr J* 12:48, 2013.

82. Martens, E. A., and Westerterp-Plantenga, M. S. Protein diets, body weight loss and weight maintenance. *Curr Opin Clin Nutr Metab Care* 17:75–79, 2014.

83. Frackelmann, K. Diet drug debacle: How two federally approved weight-loss drugs crashed. *Science News* 152:252–253, 1997.

84. U.S. Food and Drug Administration. *Beware of Products Promising Miracle Weight Loss.* Available online at http://www.fda.gov/ForConsumers/ConsumerUpdates/ucm246742.htm. Accessed February 11, 2015.

85. Manore, M. M. Dietary supplements for improving body composition and reducing body weight: Where is the evidence? *Int J Sport Nutr Exerc Metab* 22:139–154, 2012.

86. Chan, T. Y. Potential risks associated with the use of herbal anti-obesity products. *Drug Saf* 32:453–456, 2009.

87. Lautz, D., Goebel-Fabbri, A., Halperin, F., and Goldfien, A. B. The great debate: Medicine or surgery. What is best for the patient with type 2 diabetes? *Diabetes Care* 34:763–770, 2011.

88. Buchwald, H., Estok, R., Fahrbach, K., et al. Weight and type 2 diabetes after bariatric surgery: Systematic review and meta-analysis. *Am J Med* 122:248–256, 2009.

89. Pontiroli, A. E., and Morabito, A. Long-term prevention of mortality in morbid obesity through bariatric surgery: A systematic review and meta-analysis of trials performed with gastric banding and gastric bypass. *Ann Surg* 253:484–487, 2011.

90. McEwen, L. N., Coelho, R. B., Baumann, L. M., et al. The cost, quality of life impact, and cost-utility of bariatric surgery in a managed care population. *Obes Surg* 20:919–928, 2010.

91. Mann, D. Weight loss surgery insurance coverage. Consumer guide to bariatric surgery. Available online at http://www.yourbariatricsurgeryguide.com/insurance. Accessed January 9, 2015.

92. Chang, S. H., Stoll, C. R., Song, J., et al. The effectiveness and risks of bariatric surgery: An updated systematic review and meta-analysis, 2003–2012. *JAMA Surg* 149:275–287, 2014.

93. Online Surgery. *Advantages and Disadvantages of Bariatric Surgery*. Available online at http://www.onlinesurgery.com/article/advantages-and-disadvantages-of-bariatric-surgery.html. Accessed February 11, 2015.

94. Klein, S., Fontana, L., Young, V. L., et al. Absence of an effect of liposuction on insulin action and risk factors for coronary heart disease. *N Engl J Med* 350:2549–2557, 2004.

FOCUS ON Eating Disorders

1. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*, 5th ed. Arlington, VA: American Psychiatric Publishing, 2013.

2. Starr, T. B., and Kreipe, R. E. Anorexia nervosa and bulimia nervosa: Brains, bones and breeding. *Curr Psychiatry Rep* 16:441, 2014.

3. Hinney, A., and Volckmar, A. L. Genetics of eating disorders. *Curr Psychiatry Rep* 15:423, 2013.

4. Valette, M., Bellisle, F., Carette, C., et al. Eating behaviour in obese patients with melanocortin-4 receptor mutations: A literature review. *Int J Obes (Lond)* 37:1027–1035, 2013.

5. Rikani, A. A., Choudhry, Z., Choudhry, A. M., et al. A critique of the literature on etiology of eating disorders. *Ann Neurosci* 20:157–161, 2013.

6. Stice, E., Ng, J., and Shaw, H. Risk factors and prodromal eating pathology. *J Child Psychol Psychiatry* 51:518–525, 2010.

7. Zeeni, N., Gharibeh, N., and Katsounari, I. The influence of sociocultural factors on the eating attitudes of Lebanese and Cypriot students: A cross-cultural study. *J Hum Nutr Diet* 26(suppl 1):45–52, 2013.

8. Becker, A. E. Television, disordered eating, and young women in Fiji: Negotiating body image and identity during rapid social change. *Cult Med Psychiatry* 28:533–559, 2004.

9. HealthyPlace. *Eating Disorders: Body Image and Advertising*, December 11, 2008. Available online at http://www.healthyplace.com/eating-disorders/main/eating-disorders-body-image-and-advertising/menu-id-58. Accessed February 5, 2015.

10. Smink, F. R., van Hoeken, D., and Hoek, H. W. Epidemiology, course, and outcome of eating disorders. *Curr Opin Psychiatry* 26:543–548, 2013.

11. Rome, E. S. Eating disorders in children and adolescents. *Curr Probl Pediatr Adolesc Health Care* 42:28–44, 2012.

12. Arcelus, J., Mitchell, A. J., Wales, J., and Nielsen, S. Mortality rates in patients with anorexia nervosa and other eating disorders. A meta-analysis of 36 studies. *Arch Gen Psychiatry* 68:724–731, 2011.

13. Peat, C., Mitchell, J. E., Hoek, H. W., and Wonderlich, S. Validity and utility of subtyping anorexia nervosa. *Int J Eat Disord* 42:1–7, 2009.

14. Misra, M., Katzman, D. K., Clarke, H., et al. Hip structural analysis in adolescent boys with anorexia nervosa and controls. *J Clin Endocrinol Metab.* 98:2952–2958, 2013.

15. American Dietetic Association. Position of the American Dietetic Association: Nutrition intervention in the treatment of eating disorders. *J Am Diet Assoc* 111:1236–1241, 2011.

16. Le Grange, D., and Lock, J. *Family-Based Treatment of Adolescent Anorexia Nervosa: The Maudsley Approach*. Available online at http://www.maudsleyparents.org/whatismaudsley.html. Accessed February 5, 2015.

17. Vandereycken, W. History of anorexia nervosa and bulimia nervosa. In *Eating Disorders and Obesity: A Comprehensive Handbook*, 2nd ed. C. G. Fairburn and K. D. Brownell, Eds. New York: Guilford Press, 2002, pp. 151–154.

18. Kaye, W. H., Weltzin, T. E., McKee, M., et al. Laboratory assessment of feeding behavior in bulimia nervosa and healthy women. Methods of developing a human feeding laboratory. *Am J Clin Nutr* 55:372–380, 1992.

19. Kaye, W. H., Weltzin, T. E., Hsu, L. K., et al. Amount of calories retained after binge eating and vomiting. *Am J Psychiatry* 150:969–971, 1993.

20. National Eating Disorders Association. *Binge Eating Disorder*. Available online at https://www.nationaleatingdisorders.org/binge-eating-disorder. Accessed February 5, 2015.

21. Healthier You. *Binge Eating Disorder*. Available online at http://www.healthieryou.com/binge.html. Accessed February 10, 2015.

22. Andersen, A. E., and Holman, J. E. Males with eating disorders: Challenges for treatment and research. *Psychopharmacol Bull* 33:391–397, 1997.

23. Spann, N., and Pritchard, M. Disordered eating in men: A look at perceived stress and excessive exercise. *Eat Weight Disord* 13:e25–e27, 2008.

24. Wooldridge, T., and Lytle, P. P. An overview of anorexia nervosa in males. *Eat Disord* 20:368–378, 2012.

25. Mehler, P. S., Sabel, A. L., Watson, T., and Andersen, A. E. High risk of osteoporosis in male patients with eating disorders. *Int J Eat Disord* 41:666–672, 2008.

26. Ward, V. B. Eating disorders in pregnancy. *BMJ* 336:93–96, 2008.

27. Linna, M. S., Raevuori, A., Haukka, J., et al. Pregnancy, obstetric, and perinatal health outcomes in eating disorders. *Am J Obstet Gynecol* 211:392.e1–e8, 2014.

28. Jacka, F. N., Ystrom, E., Brantsaeter, A. L., et al. Maternal and early postnatal nutrition and mental health of offspring by age 5 years: A prospective cohort study. *J Am Acad Child Adolesc Psychiatry* 52:1038–1047, 2013.

29. Campbell, K., and Peebles, R. Eating disorders in children and adolescents: State of the art review. *Pediatrics* 134:582–592, 2014.

30. Bratland-Sanda, S., and Sundgot-Borgen, J. Eating disorders in athletes: Overview of prevalence, risk factors and recommendations for prevention and treatment. *Eur J Sport Sci* 13:499–508, 2013.

31. Sundgot-Borgen, J., and Torstveit, M. K. Prevalence of eating disorders in elite athletes is higher than in the general population. *Clin J Sports Med* 14:25–32, 2004.

32. El Ghoch, M., Soave, F., Calugi, S., and Dalle Grave, R. Eating disorders, physical fitness and sport performance: A systematic review. *Nutrients* 5:5140–5160, 2013.

33. De Souza, M. J., Nattiv, A., Joy, E., et al. 2014 Female Athlete Triad Coalition consensus statement on treatment and return to play of the female athlete triad: 1st International Conference held in San Francisco, CA, May 2012, and 2nd International Conference held in Indianapolis, IN, May 2013. *Clin J Sport Med.* 24:96–119, 2014.

34. Lambrinoudaki, I., and Papadimitriou, D. Pathophysiology of bone loss in the female athlete. *Ann NY Acad Sci* 1205:45–50, 2010.

35. Mountjoy, M., Sundgot-Borgen, J., Burke, L., et al. The IOC consensus statement: Beyond the female athlete triad—relative energy deficiency in sport (RED-S). *Br J Sports Med* 48:491–497, 2014.

36. Larrañaga, A., Docet, M. F., and García-Mayor, R. V. Disordered eating behaviors in type 1 diabetic patients. *World J Diabetes* 2:189–195, 2011.

37. Davidson, J. Diabulimia: How eating disorders can affect adolescents with diabetes. *Nurs Stand* 29:44–49, 2014.

Chapter 8

1. Fulgoni, 3rd, V. L., Keast, D. R., Bailey, R. L., and Dwyer, J. Foods, fortificants, and supplements: Where do Americans get their nutrients? *J Nutr* 141:1847–1854, 2011.

2. Berner, L. A., Keast, D. R., Bailey, R. L., and Dwyer, J. T. Fortified foods are major contributors to nutrient intakes in diets of US children and adolescents. *J Acad Nutr Diet* 114:1009–1022, 2014.

3. Valerie, T. Discretionary fortification—A public health perspective. *Nutrients* 6:4421–4433, 2014.

4. Butterworth, R. F. Thiamin. In *Modern Nutrition in Health and Disease*, 10th ed. M. E. Shils, M. Shike, A. C. Ross, et al., Eds. Philadelphia: Lippincott Williams & Wilkins, 2006, pp. 426–433.

5. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B-6, Folate, Vitamin B-12, Pantothenic Acid, Biotin, and Choline*. Washington, DC: National Academies Press, 1998.

6. Saffert, A., Pieper, G., and Jetten, J. Effect of package light transmittance on vitamin content of milk. *Technol Sci* 21:47–55, 2008.

7. Roe, D. A. *A Plague of Corn: The Social History of Pellagra*. Ithaca, NY: Cornell University Press, 1973.

8. Syndenstricker, V. P. The history of pellagra, its recognition as a disorder of nutrition and its conquest. *Am J Clin Nutr* 6:409–441, 1958.

9. Park, Y. K., Sempos, C. T., Barton, C. N., et al. Effectiveness of food fortification in the United States: The case of pellagra. *Am J Public Health* 90:727–738, 2000.

10. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes: Guiding Principles for Nutrition Labeling and Fortification*. Washington, DC: National Academies Press, 2003.

11. Seal, A. J., Creeke, P. I., Dibari, F., et al. Low and deficient niacin status and pellagra are endemic in postwar Angola. *Am J Clin Nutr* 85:218–242, 2007.

12. Song, W. L., and FitzGerald, G. A. Niacin, an old drug with a new twist. *J Lipid Res* 54:2586–25894, 2013.

13. Bessey, O. A., Adam, D. J., and Hansen, A. E. Intake of vitamin B_6 and infantile convulsions: A first approximation of requirements of pyridoxine in infants. *Pediatrics* 20:33–44, 1957.

14. Rios-Avila, L., Coats, B., Chi, Y. Y., et al. Metabolite profile analysis reveals association of vitamin B-6 with metabolites related to one-carbon metabolism and tryptophan catabolism but not with biomarkers of inflammation in oral contraceptive users and reveals the effects of oral contraceptives on these processes. *J Nutr* 145:87–95, 2015.

15. Ganguly, P., and Alam, S. F. Role of homocysteine in the development of cardiovascular disease. *Nutr J* 14:6, 2015.

16. Martí-Carvajal, A. J., Solà , I., and Lathyris, D. Homocysteine-lowering interventions for preventing cardiovascular events. *Cochrane Database Syst Rev* 1:CD006612, 2015.

17. Talebi, M., Andalib, S., Bakhti, S., et al. Effect of vitamin B_6 on clinical symptoms and electrodiagnostic results of patients with carpal tunnel syndrome. *Adv Pharm Bull* 3:283–288, 2013.

18. Biggs, W. S., and Demuth, R. H. Premenstrual syndrome and premenstrual dysphoric disorder. *Am Fam Physician* 84:918–924, 2011.

19. Williams, J., Mai, C. T., Mulinare, J., et al. Updated estimates of neural tube defects prevented by mandatory folic acid fortification—United States, 1995–2011. *Morb Mortal Wkly Rep* 64:1–5, 2015.

20. Crider, K. S., Bailey, L. B., and Berry, R. J. Folic acid food fortification—Its history, effect, concerns, and future directions. *Nutrients* 3:370–384, 2011.

21. Chen, P., Li, C., Li, X., et al. Higher dietary folate intake reduces the breast cancer risk: A systematic review and meta-analysis. *Br J Cancer* 110:2327–2338, 2014.

22. Tárraga López, P. J., Albero, J. S., and Rodríguez-Montes, J. A. Primary and secondary prevention of colorectal cancer. *Clin Med Insights Gastroenterol* 7:33–46, 2014.

23. Tio, M., Andrici, J., Cox, M. R., and Eslick, G. D. Folate intake and the risk of upper gastrointestinal cancers: A systematic review and meta-analysis. *J Gastroenterol Hepatol* 29:250–258, 2014.

24. Qin, X., Cui, Y., Shen, L., et al. Folic acid supplementation and cancer risk: A meta-analysis of randomized controlled trials. *Int J Cancer* 133:1033–1041, 2013.

25. National Institutes of Health Office of Dietary Supplements. *Folate: Dietary Supplement Fact Sheet.* Available online at http://ods.od.nih.gov/factsheets/Folate-HealthProfessional. Accessed February 14, 2015.

26. Craig, W.J., Mangels, A.R.; American Dietetic Association. Position of the American Dietetic Association: Vegetarian diets. *J Am Diet Assoc* 109:1266–1282, 2009.

27. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. Washington, DC: National Academies Press, 2000.

28. Thomas, L. D., Elinder, C. G., Tiselius, H. G., et al. Ascorbic acid supplements and kidney stone incidence among men: A prospective study. *JAMA Intern Med* 173:386–388, 2013.

29. Hemilä, H., and Chalker, E. Vitamin C for preventing and treating the common cold. *Cochrane Database Syst Rev* 1:CD000980, 2013.

30. Wang, Y., Chun, O. K., and Song, W. O. Plasma and dietary antioxidant status as cardiovascular disease risk factors: A review of human studies. *Nutrients* 5:2969–3004, 2013.

31. Potter, J. D. The failure of cancer chemoprevention. *Carcinogenesis* 35:974–982, 2014.

32. Du, J., Cullen, J. J., and Buettner, G. R. Ascorbic acid: Chemistry, biology and the treatment of cancer. *Biochim Biophys Acta* 1826:443–457, 2012.

33. Jacobs, C., Hutton, B., Ng, T., et al. Is there a role for oral or intravenous ascorbate (vitamin C) in treating patients with cancer?: A systematic review. *Oncologist*, 20:210–223, 2015.

34. Zeisel, S. H., and da Costa, K. A. Choline: An essential nutrient for public health. *Nutr Rev* 67:615–623, 2009.

35. Patterson, K. Y., Bhagwat, S. A., Williams, J. R., et al. *USDA Database for the Choline Content of Common Foods, Release Two, January 2008*. Available online at www.ars.usda.gov/SP2UserFiles/Place/12354500/Data/Choline/Choln02.pdf. Accessed February 3, 2015.

Chapter 9

1. Thacher, T. D., Fischer, P. R., Tebben, P. J., et al. Increasing incidence of nutritional rickets: a population-based study in Olmsted County, Minnesota. *Mayo Clin Proc* 88:176–183, 2013.

2. Weisberg, P., Scanlon, K. S., Li, R., and Cogswell, M. E. Nutritional rickets among children in the United States: Review of cases reported between 1986 and 2003. *Am J Clin Nutr* 80(suppl):1697S–1705S, 2004.

3. Holden, J. M., Eldridge, A. L., Beecher, G. R., et al. Carotenoid content of U.S. foods: An update of the database. *J Food Composition Anal* 12:169–196, 1999.

4. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes: Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. Washington, DC: National Academies Press, 2001.

5. Ross, A. C. Vitamin A and carotenoids. In *Modern Nutrition in Health and Disease*, 10th ed. M. E. Shils, M. Shike, A. C. Ross, et al., Eds. Philadelphia: Lippincott Williams & Wilkins, 2006, pp. 351–375.

6. World Health Organization. *Micronutrient Deficiencies: Vitamin A Deficiency: The Challenge.* Available online at http://www.who.int/nutrition/topics/vad/en/index.html. Accessed January 28, 2014.

7. Enserink, M. Tough lessons from golden rice. *Science* 320:468–471, 2008.

8. Tang, G., Hu, Y., Yin, S. A., et al. β-Carotene in Golden Rice is as good as β-carotene in oil at providing vitamin A to children. *Am J Clin Nutr* 96:658–664, 2012.

9. Greenpeace International. *Golden Rice's Lack of Luster: Addressing Vitamin A Deficiency without Genetic Engineering,* November 9, 2010. Available online at http://www.greenpeace.org/international/en/publications/reports/Golden-rice-report-2010. Accessed March 1, 2015.

10. Bienvenido, O. J. *Rice in Human Nutrition*. Available online at http://www.fao.org/docrep/t0567e/T0567E00.htm#Contents. Accessed March 1, 2015.

11. Greenpeace International. *The Golden Rice Illusion*. Available online at http://www.greenpeace.org/international/en/campaigns/agriculture/problem/genetic-engineering/Greenpeace-and-Golden-Rice. Accessed March 1, 2015.

12. Potrykus, I. Lessons from the "Humanitarian Golden Rice" project: Regulation prevents development of public good genetically engineered crop products. *N Biotechnol* 27:466–472, 2010.

13. Moghissi, A. A., Pei, S., and Liu, Y. Golden Rice: Scientific, regulatory and public information processes of a genetically modified organism. *Crit Rev Biotechnol* 15:1–7, 2015.

14. Conner, S. *Former Greenpeace Leading Light Condemns Them for Opposing GM "Golden Rice" Crop That Could Save Two Million Children from Starvation per Year*, January 30, 2014. Available online at http://www.independent.co.uk/news/science/former-greenpeace-leading-light-condemns-them-for-opposing-gm-golden-rice-crop-that-could-save-two-million-children-from-starvation-per-year-9097170.html. Accessed February 11, 2015.

15. *Allow Golden Rice Now!* Available online at http://www.allowgoldenricenow.org. Accessed February 11, 2015.

16. Golden Rice Project. *Pope Blesses Golden Rice*. Available online at http://www.goldenrice.org. Accessed February 12, 2015.

17. U.S. Department of Agriculture, Agricultural Research Service. Table 1: Nutrient intakes from food and beverages: Mean amounts consumed per individual by gender and age, in the United States, 2011–2012. *What We Eat in America* (NHANES 2011–2012). Available online at http://www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/1112/Table_1_NIN_GEN_11.pdf. Accessed February 11, 2015.

18. Wintergerst, E. S., Maggini, S., and Hornig, D. H. Contribution of selected vitamins and trace elements to immune function. *Ann Nutr Metab* 51:301–323, 2007.

19. Penniston, K. L., and Tanumihardjo, S. A. The acute and chronic toxic effects of vitamin A. *Am J Clin Nutr* 83:191–201, 2006.

20. Castaño, G., Etchart, C., and Sookoian, S. Vitamin A toxicity in a physical culturist patient: A case report and review of the literature. *Ann Hepatol* 5:293–395, 2006.

21. Adams, J. The neurobehavioral teratology of retinoids: A 50-year history. *Birth Defects Res A Clin Mol Teratol* 88:895–905, 2010.

22. Goralczyk, R. Beta-carotene and lung cancer in smokers: Review of hypotheses and status of research. *Nutr Cancer* 61:767–774, 2009.

23. Holick, M. F. Sunlight, ultraviolet radiation, vitamin D and skin cancer: How much sunlight do we need? *Adv Exp Med Biol* 810:1–16, 2014.

24. Wacker, M., and Holick, M. F. Vitamin D—Effects on skeletal and extraskeletal health and the need for supplementation. *Nutrients* 5:111–148, 2013.

25. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Calcium and Vitamin D.* Washington, DC: National Academies Press, 2011.

26. Gröber, U., Spitz, J., Reichrath, J., et al. Vitamin D: Update 2013: From rickets prophylaxis to general preventive healthcare. *Dermatoendocrinol* 5:331–347, 2013.

27. Holick, M. F., and Chen, T. C. Vitamin D deficiency: A worldwide problem with health consequences. *Am J Clin Nutr* 87(suppl):1080S–1086S, 2008.

28. Holick, M. F. Vitamin D deficiency: What a pain it is. *Mayo Clin Proc* 78:1457–1459, 2003.

29. Holick, M. F. Vitamin D: Importance in the prevention of cancers, type 1 diabetes, heart disease, and osteoporosis. *Am J Clin Nutr* 79:362–371, 2004.

30 Holick, M. F. Sunlight and vitamin D for bone health and prevention of autoimmune diseases, cancers, and cardiovascular disease. *Am J Clin Nutr* 80(suppl):1678S–1688S, 2004.

31. Cashman, K. D. Vitamin D: Dietary requirements and food fortification as a means of helping achieve. *J Steroid Biochem Mol Biol* 148:19–26, 2015.

32. American Academy of Pediatrics Section on Breastfeeding. Policy statement: Breastfeeding and the use of human milk. *Pediatrics* 129:e827–e841, 2012.

33. Wagner, C. L., and Greer, F. R. American Academy of Pediatrics Section on Breastfeeding, American Academy of Pediatrics Committee on Nutrition: Prevention of rickets and vitamin D deficiency in infants, children, and adolescents. *Pediatrics* 122:1142–1152, 2008.

34. Office of Dietary Supplements. *Dietary Supplement Fact Sheet: Vitamin D.* Available online at http://ods.od.nih.gov/factsheets/vitamind.asp. Accessed March 1, 2015.

35. Blank, S., Scanlon, K. S., Sinks, T. H., and Falk, H. An outbreak of hypervitaminosis D associated with the overfortification of milk from a home-delivery dairy. *Am J Public Health* 85:656–659, 1995.

36. Borel, P., Preveraud, D., and Desmarchelier, C. Bioavailability of vitamin E in humans: An update. *Nutr Rev* 71:319–331, 2013.

37. Sabat, R., Guthmann, F., and Rüstow, B. Formation of reactive oxygen species in lung alveolar cells: Effect of vitamin E deficiency. *Lung* 186:115–122, 2008.

38. Rizvi, S., Raza, S. T., Ahmed, F., et al. The role of vitamin E in human health and some diseases. *Sultan Qaboos Univ Med J* 14:e157–e165, 2014.

39. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. Washington, DC: National Academies Press, 2000.

40. Traber M. G. Vitamin E inadequacy in humans: Causes and consequences. *Adv Nutr* 5:503–514, 2014.

41. Cordero, Z., Drogan, D., Weikert, C., and Boeing, H. Vitamin E and risk of cardiovascular diseases: A review of epidemiologic and clinical trial studies. *Crit Rev Food Sci Nutr* 50:420–440, 2010.

42. Fortmann, S. P., Burda, B. U., Senger, C. A., et al. Vitamin and mineral supplements in the primary prevention of cardiovascular disease and cancer: An updated systematic evidence review for the U.S. Preventive Services Task Force. *Ann Intern Med* 159:824–834, 2013.

43. Vardi, M., Levy, N. S., and Levy, A. P. Vitamin E in the prevention of cardiovascular disease: The importance of proper patient selection. *J Lipid Res* 54:2307–2314, 2013.

44. Vermeer, C. Vitamin K: The effect on health beyond coagulation—An overview. *Food Nutr Res (Online),* April 2, 2012, 56, doi:10.3402/fnr.v56i0.5329.

45. Willems, B. A., Vermeer, C., Reutelingsperger, C. P., and Schurgers, L. J. The realm of vitamin K dependent proteins: Shifting from coagulation toward calcification. *Mol Nutr Food Res* 58:1620–1635, 2014.

46. Theuwissen, E., Magdeleyns, E. J., Braam, L. A., et al. Vitamin K status in healthy volunteers. *Food Funct* 5:229–234, 2014.

47. Council for Responsible Nutrition. *New Survey Reveals High Percentage of U.S. Population Take Dietary Supplements—and with High Confidence*. Available online at http://www.crnusa.org/CRNPR14-CRNCCSurvey103014.html. Accessed July 15, 2015.

48. Guallar, E., Stranges, S., Mulrow, C., et al. Enough is enough: Stop wasting money on vitamin and mineral supplements. *Ann Intern Med* 159:850–851, 2013.

49. American Dietetic Association. Position of the American Dietetic Association: Nutrient supplementation. *J Am Diet Assoc* 109:2073–2085, 2009.

50. Bruno, R. S., and Traber, M. G. Cigarette smoke alters human vitamin E requirements. *J Nutr* 135:671–674, 2005.

FOCUS ON Phytochemicals

1. Ozen, A. E., Pons, A., and Tur, J. A. Worldwide consumption of functional foods: A systematic review. *Nutr Rev* 70:472–481, 2012.

2. Chen, L., Xin, X., Yuan, Q., et al. Phytochemical properties and antioxidant capacities of various colored berries. *J Sci Food Agric* 94:180–188, 2014.

3. Edel, A. L., Rodriguez-Leyva, D., Maddaford, T. G., et al. Dietary flaxseed independently lowers circulating cholesterol and lowers it beyond the effects of cholesterol-lowering medications alone in patients with peripheral artery disease. *J Nutr* 145:749–757, 2015.

4. Khalesi, S., Irwin C., and Schubert, M. Flaxseed consumption may reduce blood pressure: A systematic review and meta-analysis of controlled trials. *J Nutr* 145:758–765, 2015.

5. Sarriá, B., Martínez-López, S., Sierra-Cinos, J. L., et al. Regular consumption of a cocoa product improves the cardiometabolic profile in healthy and moderately hypercholesterolaemic adults. *Br J Nutr* 111:122–134, 2014.

6. Butt, M. S., Sultan, M. T., Butt, M. S., and Iqbal, J. Garlic: Nature's protection against physiological threats. *Crit Rev Food Sci Nutr* 49:538–551, 2009.

7. Carpentier, S., Knaus, M., and Suh, M. Associations between lutein, zeaxanthin, and age-related macular degeneration: An overview. *Crit Rev Food Sci Nutr* 49:313–326, 2009.

8. Párraga-Martínez, I., López-Torres-Hidalgo, J. D., Del Campo-Del Campo, J. M., et al. Long-term effects

of plant stanols on the lipid profile of patients with hypercholesterolemia. A randomized clinical trial. *Rev Esp Cardiol (Engl Ed)* 68:665–671, 2015.

9. Bao, Y., Han, J., Hu, F. B., et al. Association of nut consumption with total and cause-specific mortality. *N Engl J Med* 369:2001–2011, 2013.

10. Guo, L., Tong, L. T., Liu, L., et al. The cholesterol-lowering effects of oat varieties based on their difference in the composition of proteins and lipids. *Lipids Health Dis* 13:1476–1511, 2014.

11. Cosman, F., de Beur, S. J., LeBoff, M. S., et al. Clinician's guide to prevention and treatment of osteoporosis. *Osteoporos Int* 25:2359–2381, 2014.

12. Raatz, S. K., Silverstein, J. T., Jahns, L., and Picklo, M. J. Issues of fish consumption for cardiovascular disease risk reduction. *Nutrients* 5:1081–1097, 2014.

13. Yu, F., Jin, Z., Jiang, H., et al. Tea consumption and the risk of five major cancers: A dose–response meta-analysis of prospective studies. *BMC Cancer* 14:197–217, 2014.

14. Lillioja, S., Neal, A. L., Tapsell, L., and Jacobs, D. R. Whole grains, type 2 diabetes, coronary heart disease, and hypertension: Links to the aleurone preferred over indigestible fiber. *BioFactors* 39:242–258, 2014.

15. Hillman, G. G., Singh-Gupta, V., Hoogstra, D. J., et al. Differential effect of soy isoflavones in enhancing high intensity radiotherapy and protecting lung tissue in a pre-clinical model of lung carcinoma. *Radiother Oncol* 109:117–125, 2013.

16. U.S. Department of Agriculture. *How Plants Protect Us: Unmasking the Secret Power of Phytochemicals.* Available online at http://www.ars.usda.gov/News/docs.htm?docid=18510. Accessed March 20, 2015.

17. Fiedor, J., and Burda, K. Potential role of carotenoids as antioxidants in human health and disease. *Nutrients* 6:466–488, 2014.

18. Kelkel, M., Schumacher, M., Dicato, M., and Diederich, M. Antioxidant and anti-proliferative properties of lycopene. *Free Radic Res* 45:925–940, 2011.

19. Ma, L., Dou, H. L., Wu, Y. Q., et al. Lutein and zeaxanthin intake and the risk of age-related macular degeneration: A systematic review and meta-analysis. *Br J Nutr* 107:350–359, 2012.

20. Kumar, S., and Pandey, A. K. Chemistry and biological activities of flavonoids: An overview. *ScientificWorldJournal* 2013:162750, 2013.

21. Li ,Y., Wicha, M. S., Schwartz, S. J., and Sun, D. Implications of cancer stem cell theory for cancer chemoprevention by natural dietary compounds. *J Nutr Biochem* 22:799–806, 2011.

22. Wang, J., and Jiang, Y. F. Natural compounds as anticancer agents: Experimental evidence. *World J Exp Med* 2:45–57, 2012.

23. Mikaili, P., Maadirad, S., Moloudizargari, M., et al. Therapeutic uses and pharmacological properties of garlic, shallot, and their biologically active compounds. *Iran J Basic Med Sci* 16:1031–1048, 2013.

24. Rice, S., and Whitehead, S. A. Phytoestrogens oestrogen synthesis and breast cancer. *J Steroid Biochem Mol Biol* 108:186–195, 2008.

25. Fisher, W. I., Johnson, A. K., Elkins, G. R., et al. Risk factors, pathophysiology, and treatment of hot flashes in cancer. *CA Cancer J Clin* 63:167–192, 2013.

26. Park, C. Y., and Weaver, C. M. Vitamin D interactions with soy isoflavones on bone after menopause: A review. *Nutrients* 4:1610–1621, 2014.

27. Hilakivi-Clarke, L., Andrade, J. E., and Helferich, W. Is soy consumption good or bad for the breast? *J Nutr* 140:2326S–2334S, 2010.

28. Jenkins, D. J., Kendall, C. W., Marchie, A., et al. Direct comparison of a dietary portfolio of cholesterol-lowering foods with a statin in hypercholesterolemic participants. *Am Clin Nutr* 81:380–387, 2005.

29. Wang, X., Ouyang, Y., Liu, J., et al. Fruit and vegetable consumption and mortality from all causes, cardiovascular disease, and cancer: Systematic review and dose-response meta-analysis of prospective cohort studies *BMJ* 349:g4490, 2014.

30. U.S. Departement of Agriculture and U.S. Department of Health and Human Services. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Available online at http://health.gov/dietaryguidelines/2015-scientific-report/pdfs/scientific-report-of-the-2015-dietary-guidelines-advisory-committee.pdf. Accessed January 17, 2016.

31. Moore, L. V., and Thompson, F. E. Adults meeting fruit and vegetable intake recommendations—United States, 2013. *MMWR Morb Mortal Wkly Rep* 64:709–713, 2015.

32. Adom, K. K., Sorrells, M. E., and Liu, R. H. Phytochemicals and antioxidant activity of milled fractions of different wheat varieties. *J Agric Food Chem* 53:2297–2306, 2005.

Chapter 10

1. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Water, Salt and Potassium*. Washington, DC: National Academies Press, 2004.

2. Sheng, H.-P. Body fluids and water balance. In *Biochemical and Physiological Aspects of Human Nutrition*, 2nd ed. M. Stipanuk, Ed. St. Louis: Saunders Elsevier, 2006, pp. 973–1000.

3. Cheuvront, S. N., and Kenefick, R. W. Dehydration: Physiology, assessment, and performance effects. *Compr Physiol* 4:257–285, 2014.

4. Masento, N. A., Golightly, M., Field, D. T., et al. Effects of hydration status on cognitive performance and mood. *Br J Nutr* 111:1841–1852, 2014.

5. Popkin, B. M., D'Anci, K. E., and Rosenberg, I. H. Water, hydration and health. *Nutr Rev* 68:439–458, 2010.

6. Thornton, S. N. Thirst and hydration: Physiology and consequences of dysfunction. *Physiol Behav* 100:15–21, 2010.

7. International Bottled Water Association. *Bottled Water Market*. Available online at http://www.bottledwater.org/economics/bottled-water-market. Accessed February 16, 2015.

8. U.S. Government Accountability Office. *Bottled Water: FDA Safety and Consumer Protections Are Often Less Stringent than Comparable EPA Protections for Tap Water*, June 2009. Available online at http://www.gao.gov/new.items/d09610.pdf. Accessed February 16, 2015.

9. Environmental Working Group. *Bottled Water Quality Investigation: 10 Major Brands, 38 Pollutants*, October 2008. Available online at http://www.ewg.org/research/bottled-water-quality-investigation. Accessed February 16, 2015.

10. Environmental Working Group. *National Drinking Water Database*. Available online at http://www.ewg.org/tap-water. Accessed February 16, 2015.

11. Boesler, M. Bottled water costs 2000 times as much as tap water. *Business Insider*, July 12, 2013. Available online at http://www.businessinsider.com/bottled-water-costs-2000x-more-than-tap-2013-7. Accessed February 16, 2015.

12. Ban the Bottle. *Bottled Water Facts.* Available online at http://www.banthebottle.net/bottled-water-facts. Accessed February 16, 2015.

13. Mozaffarian, D., Benjamin, E. J., Go, A. S., et al. American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics—2015 update: A report from the American Heart Association. *Circulation* 131:e29–e322, 2015.

14. American Heart Association. *Understanding Your Risk for High Blood Pressure.* Available online at http://www.heart.org/HEARTORG/Conditions/HighBloodPressure/UnderstandYourRiskforHighBloodPressure/Understand-Your-Risk-for-High-Blood-Pressure_UCM_002052_Article.jsp. Accessed February 16, 2015.

15. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.

16. Carvalho, J. J., Baruzzi, R. G., Howard, P. F., et al. Blood pressure in four remote populations in the Intersalt study. *Hypertension* 14:238–246, 1989.

17. Eckel, R. H., Jakicic, J. M., Ard, J. D., et al. 2013 AHA/ACC Guideline on Lifestyle Management to Reduce Cardiovascular Risk: A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation* 129(25 suppl 2):S76–S99, 2014.

18. Sacks, F. M., Svetkey, L. P., Vollmer, W. M., et al. Effects on blood pressure of reduced dietary sodium and the Dietary Approaches to Stop Hypertension (DASH) diet. DASH–Sodium Collaborative Research Group. *N Engl J Med* 344:3–10, 2001.

19. Houston, M. C., and Harper, K. J. Potassium, magnesium, and calcium: Their role in both the cause and treatment of hypertension. *J Clin Hypertens (Greenwich)* 10(7 suppl 2):3–11, 2008.

20. Appel, L. J., Moore, T. J., Obarzanek, E., et al. A clinical trial of the effects of dietary patterns on blood pressure. *N Engl J Med* 336:1117–1124, 1997.

21. Vogt, T. M., Appel, L. J., Obarzanek, E., et al. Dietary Approaches to Stop Hypertension: Rationale, design and methods. *J Am Diet Assoc* 99:12s–18s, 1999.

22. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Available online at http://health.gov/dietaryguidelines/2015-scientific-report/pdfs/scientific-report-of-the-2015-dietary-guidelines-advisory-committee.pdf. Accessed January 17, 2016.

23. Yokoyama, Y., Nishimura, K., Barnard, N. D., et al. Vegetarian diets and blood pressure: A meta-analysis. *JAMA Intern Med* 174:577–587, 2014.

24. Jacobson, M. F., Havas, S., and McCarter, R. Changes in sodium levels in processed and restaurant foods, 2005 to 2011. *JAMA Intern Med* 173:1285–1291, 2013.

Chapter 11

1. Hambidge, K. M., Miller, L. V., Westcott, J. E., et al. Zinc bioavailability and homeostasis. *Am J Clin Nutr* 91:1478S–1483S, 2010.

2. Gibson, R. S., Bailey, K. B., Gibbs, M., and Ferguson, E. L. A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability. *Food Nutr Bull* 31(2 suppl):S134–S146, 2010.

3. Wright, N. C., Looker, A. C., Saag, K. G., et al. The recent prevalence of osteoporosis and low bone mass in the United States based on bone mineral density at the femoral neck or lumbar spine. *J Bone Miner Res* 29:2520–2526, 2014.

4. Willems, B. A., Vermeer, C., Reutelingsperger, C. P., and Schurgers, L. J. The realm of vitamin K dependent proteins: Shifting from coagulation toward calcification. *Mol Nutr Food Res* 58:1620–1635, 2014.

5. National Institutes of Arthritis and Musculoskeletal and Skin Diseases, NIH Osteoporosis and Related Bone Diseases National Resource Center. *Peak Bone Mass in Women.* Available online at http://www.niams.nih.gov/health_info/bone/osteoporosis/bone_mass.asp. Accessed February 18, 2015.

6. Kwan, P. Osteoporosis: From osteoscience to neuroscience and beyond. *Mech Ageing Dev* 145:26–38, 2015.

7. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Available online at http://health.gov/dietaryguidelines/2015-scientific-report/pdfs/scientific-report-of-the-2015-dietary-guidelines-advisory-committee.pdf. Accessed January 17, 2016.

8. Ensrud, K. E. Epidemiology of fracture risk with advancing age. *J Gerontol A Biol Sci Med Sci* 68:1236–1242, 2013.

9. International Osteoporosis Foundation. *Facts and Statistics.* Available online at http://www.iofbonehealth.org/facts-statistics. Accessed February 27, 2015.

10. Zhu, K., and Prince, R. L. Calcium and bone. *Clin Biochem* 45:936–942, 2012.

11. Gallagher, J. C. Vitamin D and aging. *Endocrinol Metab Clin North Am* 42:319–332, 2013.

12. Cawthon, P. M. Gender differences in osteoporosis and fractures. *Clin Orthop Relat Res* 469:1900–1905, 2011.

13. Clark, G. R., and Duncan, E. L. The genetics of osteoporosis. *Br Med Bull* 113:73–81, 2015.

14. Redmond, J., Jarjou, L. M., Zhou, B., et al. Ethnic differences in calcium, phosphate and bone metabolism. *Proc Nutr Soc* 73:340–351, 2014.

15. Aloia, J. F. African Americans, 25-hydroxyvitamin D, and osteoporosis: A paradox. *Am J Clin Nutr* 88:545S–550S, 2008.

16. Abrahamsen, B., Brask-Lindemann, D., Rubin, K. H., and Schwarz, P. A review of lifestyle, smoking and other modifiable risk factors for osteoporotic fractures. *Bonekey Rep* 3:574, 2014.

17. Maurel, D. B., Boisseau, N., Benhamou, C. L., and Jaffre, C. Alcohol and bone: Review of dose effects and mechanisms. *Osteoporos Int* 23:1–16, 2012.

18. Kelley, G. A., Kelley, K. S., and Kohrt, W. M. Exercise and bone mineral density in premenopausal women: A meta-analysis of randomized controlled trials. *Int J Endocrinol* 2013:741639, 2013.

19. Kemmler, W., and von Stengel, S. Dose–response effect of exercise frequency on bone mineral density in post-menopausal, osteopenic women. *Scand J Med Sci Sports* 24:526–534, 2014.

20. Johansson, H., Kanis, J. A., Odén, A., et al. A meta-analysis of the association of fracture risk and body mass index in women. *J Bone Miner Res* 29:223–233, 2014.

21. Salamat, M. R., Salamat, A. H., Abedi, I., and Janghorbani, M. Relationship between weight, body mass index, and bone mineral density in men referred for dual-energy x-ray absorptiometry scan in Isfahan, Iran. *J Osteoporos* 2013:205963, 2013.

22. Gonnelli, S., Caffarelli, C., and Nuti, R. Obesity and fracture risk. *Clin Cases Miner Bone Metab* 11:9–14, 2014.

23. Okada, A., Ichikawa, J., and Tozawa, K. Kidney stone formation during space. *Clin Calcium* 21:1505–1510, 2011.

24. Whedon, G. D., Lutwak, L., Rambaut, P., et al. Mineral and nitrogen metabolic studies on Skylab flights and comparison with effects of earth long-term recumbency. *Life Sci Space Res* 14:119–127, 1976.

25. Smith, S., Wastney, M., O'Brien, K., et al. Bone markers, calcium metabolism and calcium kinetics during extended-duration space flight on the Mir space station. *J Bone Miner Res* 20:208–218, 2005.

26. LeBlanc, A., Schneider, V., Shackelford, L., et al. Bone mineral and lean tissue loss after long duration space flight. *J Musculoskelet Neuronal Interact* 1:157–160, 2000.

27. Grigoriev, A. I., Oganov, V. S., Bakulin, A. V., et al. Clinical and physiological evaluation of bone changes among astronauts after long-term space flights. *Aviakos Ekolog Med* 32:21–25, 1998.

28. Shackelford, L. C., Oganov, V., LeBlanc, A., et al. *Bone Mineral Loss and Recovery After Shuttle-Mir Flights*. Available online at http://spaceflight.nasa.gov/history/shuttle-mir/science/hls/musc/sc-hls-bone.htm. Accessed March 5, 2015.

29. Smith, S. M., McCoy, T., Gazda, D., et al. Space flight calcium: Implications for astronaut health, spacecraft operations, and Earth. *Nutrients* 4:2047–2068, 2012.

30. Smith, S. M., Heer, M. A., Shackelford, L. C., et al. Benefits for bone from resistance exercise and nutrition in long-duration spaceflight: Evidence from biochemistry and densitometry. *J Bone Miner Res* 27:1896–1906, 2012.

31. Park, S. M., Jee, J., Joung, J. Y., et al. High dietary sodium intake assessed by 24-hour urine specimen increase urinary calcium excretion and bone resorption marker. *J Bone Metab* 21:189–194, 2014.

32. Nicoll, R., and McLaren Howard, J. The acid-ash hypothesis revisited: A reassessment of the impact of dietary acidity on bone. *J Bone Miner Metab* 32:469–475, 2014.

33. Mangano, K. M., Sahni, S., and Kerstetter, J. E. Dietary protein is beneficial to bone health under conditions of adequate calcium intake: An update on clinical research. *Curr Opin Clin Nutr Metab Care* 17:69–74, 2014.

34. Zeng, F. F., Wu, B. H., Fan, F., et al. Dietary patterns and the risk of hip fractures in elderly Chinese: A matched case-control study. *J Clin Endocrinol Metab* 98:2347–2355, 2013.

35. U.S. Preventive Services Task Force. *Vitamin D and Calcium to Prevent Fractures: Preventive Medication*. Available online at http://www.uspreventiveservicestaskforce.org/uspstf12/vitamind/finalrecvitd.htm. Accessed February 20, 2015.

36. Papapoulos, S. E. Use of bisphosphonates in the management of postmenopausal osteoporosis. *Ann NY Acad Sci* 1218:15–32, 2011.

37. Mangano, K. M., Walsh, S. J., Insogna, K. L., et al. Calcium intake in the United States from dietary and supplemental sources across adult age groups: New estimates from the National Health and Nutrition Examination Survey 2003–2006. *J Am Diet Assoc* 111:687–695, 2011.

38. U.S. Department of Agriculture, Agricultural Research Service. Table 37. Total nutrient intakes: Percent reporting and mean amounts of selected vitamins and minerals from food, beverages, and dietary supplements, by gender and age, in the United States, 2011–2012, What We Eat in America (NHANES 2011–2012). Available online at http://www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/1112/Table_37_SUP_GEN_11.pdf. Accessed January 21, 2016.

39. Reid, I. R., Bristow, S. M., and Bolland, M. J. Cardiovascular complications of calcium supplements. *J Cell Biochem* 116:494–501, 2015.

40. Bolland, M. J., Avenell, A., Baron, J. A., et al. Effect of calcium supplements on risk of myocardial infarction and cardiovascular events: Meta-analysis. *BMJ* 341:c3691, 2010.

41. Bolland, M., Grey, A., Avenell, A., et al. Calcium supplements with or without vitamin D and risk of cardiovascular events: Reanalysis of the Women's Health Initiative limited access dataset and meta-analysis. *BMJ* 342:d2040, 2011.

42. Prentice, R. L., Pettinger, M. B., Jackson, R. D., et al. Health risks and benefits from calcium and vitamin D supplementation: Women's Health Initiative clinical trial and cohort study. *Osteoporos Int* 24:567–580, 2013.

43. Paik, J. M., Curhan, G. C., Sun, Q., et al. Calcium supplement intake and risk of cardiovascular disease in women. *Osteoporos Int* 25:2047–2056, 2014.

44. Lewis, J. R., Radavelli-Bagatini, S., Rejnmark, L., et al. The effects of calcium supplementation on verified coronary heart disease hospitalization and death in postmenopausal women:

A collaborative meta-analysis of randomized controlled trials. *J Bone Miner Res* 30:165–175, 2015.

45. Chung, M., Lee, J., Terasawa, T., et al. Vitamin D with or without calcium supplementation for prevention of cancer and fractures: An updated meta-analysis for the U.S. Preventive Services Task Force. *Ann Intern Med* 155:827–838, 2011.

46. Mozaffarian, D., Benjamin, E. J., Go, A. S., et al. Heart disease and stroke statistics—2015 update: A report from the American Heart Association. *Circulation* 131:434–441, 2015.

47. Reid, I. R., Bolland, M. J., Sambrook, P. N., and Grey, A. Calcium supplementation: Balancing the cardiovascular risks. *Maturitas* 69:289–295, 2011.

48. Kaluza, J., Orsini, N., Levitan, E. B., et al. Dietary calcium and magnesium intake and mortality: A prospective study of men. *Am J Epidemiol* 171:801–807, 2010.

49. Sipponen, P., and Härkönen, M. Hypochlorhydric stomach: A risk condition for calcium malabsorption and osteoporosis? *Scand J Gastroenterol* 45:133–138, 2010.

50. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride*. Washington, DC: National Academies Press, 1997.

51. Heaney, R. P., Weaver, C. M., and Recker, R. R. Calcium absorption from spinach. *Am J Clin Nutr* 47:707–709, 1988.

52. Conlin, P. R., Chow, D., Miller, E. R. III, et al. The effect of dietary patterns on blood pressure control in hypertensive patients: Results from the Dietary Approaches to Stop Hypertension (DASH) trial. *Am J Hypertens* 13:949–955, 2000.

53. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Calcium and Vitamin D*. Washington, DC: National Academies Press, 2011.

54. Prentice, A. Micronutrients and the bone mineral content of the mother, fetus and newborn. *J Nutr* 133(5 suppl 2):1693S–1699S, 2003.

55. Saad, L. Nearly half of Americans drink soda daily. *Gallup Well Being*, July 23, 2012. Available online athttp://www.gallup.com/poll/156116/Nearly-Half-Americans-Drink-Soda-Daily.aspx. Accessed February 20, 2015.

56. Centers for Disease Control and Prevention. *CDC Guide to Strategies for Reducing the Consumption of Sugar-Sweetened Beverages*, March 2010. Available online at http://www.cdph.ca.gov/SiteCollectionDocuments/StratstoReduce_Sugar_Sweetened_Bevs.pdf. Accessed March 4, 2015.

57. Patel, A. M., Adeseun, G. A., and Goldfarb, S. Calcium-alkali syndrome in the modern era. *Nutrients* 5:4880–4893, 2013.

58. Ríos-Castillo, I., Olivares, M., Brito, A., et al. One-month of calcium supplementation does not affect iron bioavailability: A randomized controlled trial. *Nutrition* 30:44–48, 2014.

59. Wood, R. J., and Zheng, J. J. High dietary calcium intakes reduce zinc absorption and balance in humans. *Am J Clin Nutr* 65:1803–1809, 1997.

60. Takeda, E., Yamamoto, H., Yamanaka-Okumura, H., and Taketani, Y. Increasing dietary phosphorus intake from food additives: Potential for negative impact on bone health. *Adv Nutr* 5:92–97, 2014.

61. Calvo, M. S., Moshfegh, A. J., and Tucker, K. L. Assessing the health impact of phosphorus in the food supply: Issues and considerations. *Adv Nutr* 5:104–113, 2014.

62. Rude, R. K., Singer, F. R., and Gruber, H. E. Skeletal and hormonal effects of magnesium deficiency. *J Am Coll Nutr* 28:131–141, 2009.

63. Chen, J., Yuan, Y. C., Leontiadis, G. I., and Howden, C. W. Recent safety concerns with proton pump inhibitors. *J Clin Gastroenterol* 46:93–114, 2012.

64. Rosanoff, A., Weaver, C. M., and Rude, R. K. Suboptimal magnesium status in the United States: Are the health consequences underestimated? *Nutr Rev* 70:153–164, 2012.

Chapter 12

1. Centers for Disease Control and Prevention. *FastStats: Anemia or Iron Deficiency*. Available online at http://www.cdc.gov/nchs/fastats/anemia.htm. Accessed February 23, 2015.

2. World Health Organization. *Micronutrient Deficiencies, Iron Deficiency Anemia*. Available online at http://www.who.int/nutrition/topics/ida/en. Accessed February 23, 2015.

3. Hurrell, R., and Egli, I. Iron bioavailability and dietary reference values. *Am J Clin Nutr* 91:1461S–1467S, 2010.

4. National Institutes of Health, Office of Dietary Supplements. *Dietary Supplement Fact Sheet: Iron*. Available online at http://ods.od.nih.gov/factsheets/iron-HealthProfessional. Accessed February 23, 2015.

5. Hurrell, R. F., Lynch, S., Bothwell, T., et al. Enhancing the absorption of fortification iron. A SUSTAIN Task Force report. *Intl J Vit Nutr Res* 74:387–401, 2004.

6. Crichton, R. R. Iron. In *Biochemical, Physiological, and Molecular Aspects of Human Nutrition*, 3rd ed. M. H. Stipanuk and M. A. Caudill, Eds. St. Louis: Elsevier, 2013, pp. 801–827.

7. Przybyszewska, J., and Zekanowska, E. The role of hepcidin, ferroportin, HCP1, and DMT1 protein in iron absorption in the human digestive tract. *Prz Gastroenterol* 9:208–213, 2014.

8. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes: Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. Washington, DC: National Academies Press, 2001.

9. U.S. Food and Drug Administration. *Guidance for Industry: Iron-Containing Supplements and Drugs: Label Warning Statements and Small Entity Compliance Guide*, October 17, 2003. Available online at http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/DietarySupplements/ucm073014.htm. Accessed February 23, 2015.

10. Vujić, M. Molecular basis of HFE-hemochromatosis. *Front Pharmacol* 5:42, 2014.

11. Leitman, S. F. Hemochromatosis: The new blood donor. *Hematology Am Soc Hematol Educ Program* 2013:645–650, 2013.

12. Basuli, D., Stevens, R. G., Torti, F. M., and Torti, S. V. Epidemiological associations between iron and cardiovascular disease and diabetes. *Front Pharmacol* 5:117, 2014.

13. Muñoz-Bravo, C., Gutiérrez-Bedmar, M., Gómez-Aracena, J., et al. Iron: Protector or risk factor for cardiovascular disease? Still controversial. *Nutrients* 5:2384–2404, 2013.

14. Juanola-Falgarona, M., Cándido-Fernández, J., Salas-Salvadó, J., et al. Association between serum ferritin and osteocalcin as a potential mechanism explaining the iron-induced insulin resistance. *PLoS One* 8:e76433, 2013.

15. Fonseca-Nunes, A., Jakszyn, P., and Agudo, A. Iron and cancer risk—A systematic review and meta-analysis of the epidemiological evidence. *Cancer Epidemiol Biomarkers Prev* 23:12–31, 2014.

16. Prasad, A. S. Discovery of human zinc deficiency: 50 years later. *J Trace Elem Med Biol* 26:66–69, 2012.

17. Wang, X., and Zhou, B. Dietary zinc absorption: A play of Zips and ZnTs in the gut. *IUBMB Life* 62:176–182, 2010.

18. Grider, A. Zinc, copper, and manganese. In *Biochemical, Physiological, and Molecular Aspects of Human Nutrition*, 3rd ed. M. H. Stipanuk and M. A. Caudill, Eds. St. Louis: Elsevier, 2013, pp. 828–848.

19. Prasad, A. S. Discovery of human zinc deficiency: Its impact on human health and disease. *Adv Nutr* 4:176–190, 2013.

20. Fulgoni, 3rd, V. L., Keast, D. R., Bailey, R. L., and Dwyer, J. Foods, fortificants, and supplements: Where do Americans get their nutrients? *J Nutr* 141:1847–1854, 2011.

21. Wessells, K. R., and Brown, K. H. Estimating the global prevalence of zinc deficiency: Results based on zinc availability in national food supplies and the prevalence of stunting. *PLoS One* 7:e50568, 2012.

22. Black, R. E. Global distribution and disease burden related to micronutrient deficiencies. *Nestle Nutr Inst Workshop Ser* 78:21–28, 2014.

23. National Institute of Allergy and Infectious Diseases, National Institutes of Health. *Common Colds: Protect Yourself and Others*. Available online at http://www.niaid.nih.gov/topics/commonCold/Pages/default.aspx. Accessed February 24, 2015.

24. Eby, 3rd, G. A. Zinc lozenges as cure for the common cold—A review and hypothesis. *Med Hypotheses* 74:482–492, 2010.

25. Singh, M., and Das, R. R. Zinc for the common cold. *Cochrane Database Syst Rev* 6:CD001364, 2013.

26. National Institute of Neurological Disorders and Stroke. *NINDS Wilson's Disease Information Page*. Available online at http://www.ninds.nih.gov/disorders/wilsons/wilsons.htm. Accessed February 24, 2015.

27. Mills, E. S. The treatment of idiopathic (hypochromic) anemia with iron and copper. *Can Med Assoc J* 22:175–178, 1930.

28. Mao, S., Zhang, A., and Huang, S. Meta-analysis of Zn, Cu and Fe in the hair of Chinese children with recurrent respiratory tract infection. *Scand J Clin Lab Invest* 74:561–567, 2014.

29. National Research Council, Food and Nutrition Board. *Recommended Dietary Allowances*, 10th ed. Washington, DC: National Academies Press, 1989.

30. Mehdi, Y., Hornick, J. L., Istasse, L., and Dufrasne, I. Selenium in the environment, metabolism and involvement in body functions. *Molecules* 18:3292–3311, 2013.

31. Loscalzo, J. Keshan disease, selenium deficiency, and the selenoproteome. *N Engl J Med* 370:1756–1760, 2014.

32. Clark, L. C., Combs, Jr., G. F., Turnbull, B. W., et al. Effect of selenium supplementation for cancer prevention in patients with carcinoma of the skin. *JAMA* 276:1957–1968, 1996.

33. Roman, M., Jitaru, P., and Barbante, C. Selenium biochemistry and its role for human health. *Metallomics* 6:25–54, 2014.

34. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. Washington, DC: National Academies Press, 2000.

35. Yang, G. Q., Wang, S. Z., Zhou, R. H., and Sun, S. Z. Endemic selenium intoxication of humans in China. *Am J Clin Nutr* 37:872–881, 1983.

36. Bjelakovic, G., Nikolova, D., and Gluud, C. Antioxidant supplements and mortality. *Curr Opin Clin Nutr Metab Care* 17:40–44, 2014.

37. Vrolijk, M. F., Opperhuizen, A., Jansen, E. H., et al. The shifting perception on antioxidants: The case of vitamin E and *β*-carotene. *Redox Biol* 4C:272–278, 2015.

38. Rayman, M. P. Selenium and human health. *Lancet* 379:1256–1268, 2012.

39. Evans, J. R., and Lawrenson, J. G. A review of the evidence for dietary interventions in preventing or slowing the progression of age-related macular degeneration.*Ophthalmic Physiol Opt* 34:390–396, 2014.

40. Alpha-Tocopherol, Beta Carotene Cancer Prevention Study Group. The effects of vitamin E and beta carotene on the incidence of lung cancer and other cancers in male smokers. *N Engl J Med* 330:1029–1035, 1994.

41. Klein, E. A., Thompson, Jr., I. M., Tangen, C. M., et al. Vitamin E and the risk of prostate cancer: The Selenium and Vitamin E Cancer Prevention Trial (SELECT). *JAMA* 306:1549–1556, 2011.

42. Tinkel, J., Hassanain, H., and Khouri, S. J. Cardiovascular antioxidant therapy: A review of supplements, pharmacotherapies, and mechanisms. *Cardiol Rev* 20:77–83, 2012.

43. World Health Organization. *Is It True That Lack of Iodine Really Causes Brain Damage?* Available online at http://www.who.int/features/qa/17/en. Accessed May 4, 2015.

44. Pearce, E. N., Andersson, M., and Zimmermann, M. B. Global iodine nutrition: Where do we stand in 2013? *Thyroid* 23:523–528, 2013.

45. Pearce, E. N., and Leung, A. M. The state of U.S. Iodine nutrition: How can we ensure adequate iodine for all? *Thyroid* 23:924–925, 2013.

46. Dunn, J. T. Iodine. In *Modern Nutrition in Health and Disease*, 10th ed. M. E. Shils, M. Shike, A. C. Ross, et al., Eds. Philadelphia: Lippincott Williams & Wilkins, 2006, pp. 300–311.

47. Hua, Y., Clark, S., Ren, J., and Sreejayan, N. Molecular mechanisms of chromium in alleviating insulin resistance. *J Nutr Biochem* 23:313–319, 2012.

48. Vincent, J. B. Recent advances in the nutritional biochemistry of trivalent chromium. *Proc Nutr Soc* 63:41–47, 2004.

49. Tian, H., Guo, X., Wang, X., et al. Chromium picolinate supplementation for overweight or obese adults. *Cochrane Database Syst Rev* 11:CD010063, 2013.

50. Di Luigi, L. Supplements and the endocrine system in athletes. *Clin Sports Med* 27:131–151, 2008.

51. Suksomboon, N., Poolsup, N., and Yuwanakorn, A. Systematic review and meta-analysis of the efficacy and safety of chromium supplementation in diabetes. *J Clin Pharm Ther* 39:292–306, 2014.

52. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride*. Washington, DC: National Academies Press, 1997.

53. U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation. U.S. Public Health Service recommendation for fluoride concentration in drinking water for the prevention of dental caries. *Public Health Reports* 130:July–August, 2015. Available online at http://www.publichealthreports.org/documents/PHS_2015_Fluoride_Guidelines.pdf. Accessed May 4, 2015.

54. McKay, F. S. Relation of mottled enamel to caries. *J Am Den Assoc* 15:1429–1437, 1928.

55. Dean, H. T. Endemic fluorosis and its relation to dental caries. *Public Health Rep* 53:1443–1452, 1938.

56. Achievements in public health, 1900–1999: Fluoridation of drinking water to prevent dental caries. *Morb Mortal Wkly Rep* 48:933–940, 1999.

57. National Research Council. *The Health Effects of Ingested Fluoride: Report of the Subcommittee on the Health Effects of Ingested Fluoride, Committee on Toxicology, Board of Environmental Studies and Toxicology, Commission on Life Sciences*. Washington, DC: National Academies Press, 1993.

58. Centers for Disease Control and Prevention.*Community Water Fluoridation:Water Fluoridation Data & Statistics*. Available online at http://www.cdc.gov/fluoridation/statistics/index.htm. Accessed February 25, 2015.

59. Palmer, C. A., and Gilbert, J. A., Academy of Nutrition and Dietetics. Position of the Academy of Nutrition and Dietetics: The impact of fluoride on health. *J Acad Nutr Diet* 112:1443–1453, 2012.

60. Levy, S. M., Warren, J. J., Phipps, K., et al. Effects of life-long fluoride intake on bone measures of adolescents: A prospective cohort study. *J Dent Res* 93:353–359, 2014.

61. Clark, M. B., and Slayton, R. L.; Section on Oral Health. Fluoride use in caries prevention in the primary care setting. *Pediatrics* 134:626–633, 2014.

62. Beltrán-Aguilar, E. D., Barker, L., and Dye, B. A. Prevalence and severity of dental fluorosis in the United States, 1999–2004. *NCHS Data Brief* Nov (53):1–8, 2010. Available online at http://www.cdc.gov/nchs/data/databriefs/db53.pdf. Accessed February 25, 2015.

FOCUS ON Dietary Supplements

1. Council for Responsible Nutrition. *New Survey Reveals High Percentage of U.S. Population Take Dietary Supplements—and with High Confidence*. Available online at http://www.crnusa.org/CRNPR14-CRNCCSurvey103014.html. Accessed July 15, 2015.

2. Clarke, T. C. , Black, L. I. , Stussman, B. A., et al. Trends in the Use of Complementary Health Approaches Among Adults: United States, 2002–2012. *Natl Health Stat Report* Feb 10 (79):1–16, 2015.

3. Food and Drug Administration. *A Dietary Supplement Labeling Guide*. Available online at http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/DietarySupplements/ucm2006823.htm. Accessed March 19, 2015.

4. Food and Drug Administration. Current good manufacturing practice in manufacturing, packaging, labeling, or holding operations for dietary supplements: Final rule. *Fed Regist* 72:34751–34958, June 25, 2007.

5. Gahche, J., Bailey, R., Burt, V., et al. Dietary supplement use among U.S. adults has increased since NHANES III (1988–1994). *NCHS Data Brief* Apr (61):1–8, 2011.

6. Guallar, E., Stranges, S., Mulrow, C., et al. Enough is enough: Stop wasting money on vitamin and mineral supplements. *Ann Intern Med* 159:850–851, 2013.

7. Alvare, T. S., Conte-Junior, C. A., Silva, J. T., and Paschoalin, V. M. L-Arginine does not improve biochemical and hormonal response in trained runners after 4 weeks of supplementation. *Nutr Res* 34:31–39, 2014.

8. Howatson, G., Hoad, M., Goodall, S., et al. Exercise-induced muscle damage is reduced in resistance-trained males by branched chain amino acids: A randomized, double-blind, placebo controlled study. *J Int Soc Sports Nutr* 9:20, 2012.

9. Anderson, B. M., and Ma, D. W. Are all *n*-3 polyunsaturated fatty acids created equal? *Lipids Health Dis* 8:33, 2009.

10. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans, 2010,* 7th ed. Washington, DC: U.S. Government Printing Office, December 2010.

11. Birzniece, V., Nelson, A. E., and Ho, K. K. Growth hormone and physical performance. *Trends Endocrinol Metab* 22:171–178, 2011.

12. National Institutes of Health, U.S. National Library of Medicine, Medline Plus. *Melatonin*. Available online at http://www.nlm.nih.gov/medlineplus/druginfo/natural/940.html. Accessed March 16, 2015.

13. National Institutes of Health, U.S. National Library of Medicine. DHEA. *Medline Plus.* Available online at http://www.nlm.nih.gov/medlineplus/druginfo/natural/331.html. Accessed March 16, 2015.

14. National Institutes of Health, U.S. National Library of Medicine, Medline Plus. *CoEnzyme Q*. Available online at http://www.nlm.nih.gov/medlineplus/druginfo/natural/938.html. Accessed March 16, 2015.

15. Banach, M., Serban, C., Sahebkar, A., et al.; Lipid and Blood Pressure Meta-Analysis Collaboration Group. Effects of coenzyme Q10 on statin-induced myopathy: A meta-analysis of randomized controlled trials. *Mayo Clin Proc* 90:24–34, 2015.

16. Jeukendrup, A. E., and Randell, R. Fat burners: Nutrition supplements that increase fat metabolism. *Obes Rev* 12:841–851, 2011.

17. Cooper, R., Naclerio, F., Allgrove, J., and Jimenez, A. Creatine supplementation with specific view to exercise/sports performance: An update. *J Int Soc Sports Nutr* 9:33, 2012.

18. Henrotin, Y., and Lambert, C. Chondroitin and glucosamine in the management of osteoarthritis: An update. *Curr Rheumatol Rep* 15:361, 2013.

19. National Institutes of Health, U.S. National Library of Medicine, Medline Plus. *SAM-e*. Available online at http://www.nlm.nih.gov/medlineplus/druginfo/natural/786.html. Accessed March 22, 2015.

20. Ooms, L. M., Horan, K. A., Rahman, P., et al. The role of the inositol polyphosphate 5-phosphatases in cellular function and human disease. *Biochem J* 419:29–49, 2009.

21. American Cancer Society. *Inositol Hexaphosphate*. Available online at http://www.cancer.org/treatment/treatmentsandsideeffects/complementaryandalternativemedicine/dietandnutrition/inositol-hexaphosphate. Accessed March 19, 2015.

22. Zampatti, S., Ricci, F., Cusumano, A., et al. Review of nutrient actions on age-related macular degeneration. *Nutr Res* 34:95–105, 2014.

23. Goralczyk, R. Beta-carotene and lung cancer in smokers: Review of hypotheses and status of research. *Nutr Cancer* 61:767–774, 2009.

24. Dickinson, A., Blatmanb, J., El-Dash, N., and Francod, J. C. Consumer usage and reasons for using dietary supplements: Report of a series of surveys. *J Am Coll Nutr* 33:176–182, 2014.

25. Gershwin, M. E., Borchers, A. T., Keen, C. L., et al. Public safety and dietary supplementation. *Ann NY Acad Sci* 1190:104–117, 2010.

26. National Institutes of Health, Office of Dietary Supplements. *Dietary Supplement Fact Sheets*. Available online at http://ods.od.nih.gov/factsheets/list-all. Accessed March 19, 2015.

27. Saper, R. B., Phillips, R. S., Sehgal, A., et al. Lead, mercury, and arsenic in US- and Indian-manufactured Ayurvedic medicines sold via the Internet. *JAMA* 300:915–923, 2008.

28. Schweitzer, A. Dietary supplements during pregnancy. *J Perinat Educ*15:44–45, 2006.

29. National Institutes of Health, National Center for Complementary and Alternative Medicine. *Ginkgo*. Available online at https://nccih.nih.gov/health/ginkgo. Accessed March 19, 2015.

30. Laws, K. R., Sweetnam, H., and Kondel, T. K. Is *Ginkgo biloba* a cognitive enhancer in healthy individuals? A meta-analysis. *Hum Psychopharmacol* 27:527–33, 2012.

31. Ihl, R. *Gingko biloba* extract EGb 761®: Clinical data in dementia. *Int Psychogeriatr* 24(suppl 1):S35–S40, 2012.

32. Birks, J., and Grimley Evans, J. *Ginkgo biloba* for cognitive impairment and dementia. *Cochrane Database Syst Rev* CD003120, 2009.

33. National Institutes of Health, National Center for Complementary and Alternative Medicine. *St. John's Wort*. Available online at http://nccam.nih.gov/health/stjohnswort/ataglance.htm. Accessed March 19, 2015.

34. Diamond, B. J., and Bailey, M. R. *Ginkgo biloba:* Indications, mechanisms, and safety. *Psychiatr Clin North Am* 36:73–83, 2013.

35. National Institutes of Health, National Center for Complementary and Integrative Health. *St John's Wort and Depression*. Available online at https://nccih.nih.gov/health/stjohnswort/sjw-and-depression.htm. Accessed March 19, 2015.

36. Shergis, J. L., Zhang, A. L., Zhou, W., and Xue, C. C. *Panax ginseng* in randomised controlled trials: A systematic review. *Phytother Res* 27:949–965, 2013.

37. Zeng, T., Guo, F. F., Zhang, C. L., et al. A meta-analysis of randomized, double-blind, placebo-controlled trials for the effects of garlic on serum lipid profiles. *J Sci Food Agric* 92:1892–1902, 2012.

38. National Institutes of Health, National Center for Complementary and Alternative Medicine. *Garlic*. Available online at http://nccam.nih.gov/health/garlic/ataglance.htm. Accessed March 25, 2015.

39. National Institutes of Health, National Center for Complementary and Alternative Medicine. *Echinacea*. Available online at http://nccam.nih.gov/health/echinacea/ataglance.htm. Accessed March 25, 2015.

40. National Institutes of Health, National Center for Complementary and Integrative Health. *Saw Palmetto*. Available online at https://nccih.nih.gov/health/palmetto/ataglance.htm. Accessed March 19, 2015.

41. National Institutes of Health, National Center for Complimentary and Integrative Health. *Kava*. Available online at https://nccih.nih.gov/health/kava. Accessed March 19, 2015.

Chapter 13

1. Garber, C. E., Blissmer, B., Deschenes, M. R., et al.; American College of Sports Medicine. American College of Sports Medicine position stand: Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Med Sci Sports Exerc* 43:1334–1359, 2011.

2. Lewis, J. A Systematic literature review of the relationship between stretching and athletic injury prevention. *Orthop Nurs* 33:312–320, 2014.

3. Chatzopoulos, D., Galazoulas, C., Patikas, D., and Kotzamanidis, C. Acute effects of static and dynamic stretching on balance, agility, reaction time and movement time. *J Sports Sci Med* 13:403–409, 2014.

4. Gallagher, D., Heymsfield, S., Heo, M., et al. Healthy percentage body fat ranges: An approach for developing guidelines based on body mass index. *Am J Clin Nutr* 72:694–701, 2000.

5. U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans*. Available online at http://www.health.gov/paguidelines/pdf/paguide.pdf. Accessed March 24, 2015.

6. Ahmed, H. M., Blaha, M. J., Nasir, K., et al. Effects of physical activity on cardiovascular disease. *Am J Cardiol* 109:288–295, 2012.

7. Kruk, J., and Czerniak, U. Physical activity and its relation to cancer risk: Updating the evidence. *Asian Pac J Cancer Prev* 14:3993–4003, 2013.

8. National Cancer Institute. *Physical Activity and Cancer*. Available online at http://www.cancer.gov/cancertopics/

causes-prevention/risk-factors/weight-activity/physical-activity-fact-sheet. Accessed March 8, 2015.

9. Des Guetz, G., Uzzan, B., Bouillet, T., et al. Impact of physical activity on cancer-specific and overall survival of patients with colorectal cancer. *Gastroenterol Res Pract* 2013:340851, 2013.

10. Bennell, K. L., Dobson, F., and Hinman, R. S. Exercise in osteoarthritis: Moving from prescription to adherence. *Best Pract Res Clin Rheumatol* 28:93–117, 2014.

11 Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids*. Washington, DC: National Academies Press, 2002.

12. Bitonte, R. A., and DeSanto, 2nd, D. J. Mandatory physical exercise for the prevention of mental illness in medical students. *Ment Illn* 6:5549, 2014.

13. Mammen, G., and Faulkner, G. Physical activity and the prevention of depression: A systematic review of prospective studies. *Am J Prev Med* 45:649–657, 2013.

14. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.

15. Centers for Disease Control and Prevention. *FastStats: Exercise or Physical Activity.* Available online at http://www.cdc.gov/nchs/fastats/exercise.htm. Accessed March 8, 2015.

16. Centers for Disease Control and Prevention. *Facts about Physical Activity.* Available online at http://www.cdc.gov/physicalactivity/data/facts.html. Accessed March 8, 2015.

17. Matthews, C. E., George, S. M., Moore, S. C., et al. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. *Am J Clin Nutr* 95:437–445, 2012.

18. Gulati, M., Shaw, L. J., Thisted, R. A., et al. Heart rate response to exercise stress testing in asymptomatic women: The St. James Women Take Heart project. *Circulation* 122:130–137, 2010.

19. Meeusen, R., Duclos, M., Foster, C., et al; European College of Sport Science; American College of Sports Medicine. Prevention, diagnosis, and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc* 45:186–205, 2013.

20. Ørtenblad, N., Westerblad, H., and Nielsen, J. Muscle glycogen stores and fatigue. *J Physiol* 591(pt 18):4405–4413, 2013.

21. Ament, W., and Verkerke, G. J. Exercise and fatigue. *Sports Med* 39:389–422, 2009.

22. Finsterer, J. Biomarkers of peripheral muscle fatigue during exercise. *BMC Musculoskelet Disord* 13:218, 2012.

23. Manore, M., and Thompson, J. *Sport Nutrition for Health and Performance*. Champaign, IL: Human Kinetics, 2000.

24. Rivera-Brown, A. M., and Frontera, W. R. Principles of exercise physiology: Response to acute exercise and long-term adaptations to training. *PMR* 4:797–804, 2012.

25. Rodriguez, N. R., DiMarco, N. M., and Langley, S. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *J Am Diet Assoc* 109:509–527, 2009.

26. Gibbs, A. E., Pickerman, J., and Sekiya, J. K. Weight management in amateur wrestling. *Sports Health* 1:227–230, 2009.

27. De Souza, M. J., Nattiv, A., Joy, E., et al.; Female Athlete Triad Coalition; American College of Sports Medicine; American Medical Society for Sports Medicine; American Bone Health Alliance. 2014 Female Athlete Triad Coalition consensus statement on treatment and return to play of the female athlete triad: 1st International Conference held in San Francisco, CA, May 2012, and 2nd International Conference held in Indianapolis, IN, May 2013. *Clin J Sport Med.* 24:96–119, 2014.

28. Lambrinoudaki, I., and Papadimitriou, D. Pathophysiology of bone loss in the female athlete. *Ann NY Acad Sci* 1205:45–50, 2010.

29. Mountjoy, M., Sundgot-Borgen, J., Burke, L., et al. The IOC consensus statement: Beyond the female athlete triad—Relative Energy Deficiency in Sport (RED-S). *Br J Sports Med* 48:491–497, 2014.

30. Bratland-Sanda, S., and Sundgot-Borgen, J. Eating disorders in athletes: Overview of prevalence, risk factors and recommendations for prevention and treatment. *Eur J Sport Sci* 13:499–508, 2013.

31. Tipton, K. D. Efficacy and consequences of very-high-protein diets for athletes and exercisers. *Proc Nutr Soc* 7:1–10, 2011.

32. Powers, S. K., Nelson, W. B., and Hudson, M. B. Exercise-induced oxidative stress in humans: Cause and consequences. *Free Radic Biol Med* 51:942–950, 2011.

33. Pendergast, D. R., Meksawan, K., Limprasertkul, A., and Fisher, N. M. Influence of exercise on nutritional requirements. *Eur J Appl Physiol* 111:379–390, 2011.

34. Latunde-Dada, G. O. Iron metabolism in athletes—Achieving a gold standard. *Eur J Haematol* 90:10–15, 2013.

35. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes: Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. Washington, DC: National Academies Press, 2001.

36. Angeline, M. E., Gee, A. O., Shindle, M., et al. The effects of vitamin D deficiency in athletes. *Am J Sports Med* 41:461–464, 2013.

37. Ogan, D., and Pritchett, K. Vitamin D and the athlete: Risks, recommendations, and benefits. *Nutrients* 5:1856–1868, 2013.

38. Zoorob, R., Parrish, M. E., O'Hara, H., and Kalliny, M. Sports nutrition needs: Before, during, and after exercise. *Prim Care* 40:475–486, 2013.

39. Saltin, B., and Castill, D. I. Fluid and electrolyte balance during prolonged exercise. In *Exercise, Nutrition, and Energy Metabolism*, E. S. Horton and R. I. Tergung, Eds. New York: Macmillan, 1988.

40. NOAA's National Weather Service. *Heat Index*. Available online at http://www.nws.noaa.gov/os/heat/heat_index.shtml. Accessed March 10, 2015.

41. Almond, C. S. D., Shin, A. Y., Fortescue, E. B., et al. Hyponatremia among runners in the Boston marathon. *N Engl J Med* 352:1550–1556, 2005.

42. Goulet, E. D. Dehydration and endurance performance in competitive athletes. *Nutr Rev* 70(suppl 2):S132–S136, 2012.

43. Meeusen, R., Roelands, B., and Spriet, L. L. Caffeine, exercise and the brain. *Nestle Nutr Inst Workshop Ser* 76:1–12, 2013.

44. Mora-Rodriguez, R., and Pallarés, J. G. Performance outcomes and unwanted side effects associated with energy drinks. *Nutr Rev* 72(suppl 1):108–120, 2014.

45. Berger, A. J., and Alford, K. Cardiac arrest in a young man following excess consumption of caffeinated "energy drinks." *Med J Aust* 190:41–43, 2009.

46. Clauson, K. A., Sheilds, K. M, McQueen, C. E., and Persad, N. Safety issues associated with commercially available energy drinks. *J Am Pharm Assoc* 48:e55–e63, 2008.

47. Ballard, S. L., Wellborn-Kim, J. J., and Clauson, K. A. Effects of commercial energy drink consumption on athletic performance and body composition. *Phys Sportsmen* 38:107–117, 2010.

48. Mora-Rodríguez, R., Pallarés, J. G., López-Gullón, J. M., et al. Improvements on neuromuscular performance with caffeine ingestion depend on the time-of-day. *J Sci Med Sport* 18:338–342, 2015.

49. Duchan, E., Patel, N. D., and Feucht, C. Energy drinks: A review of use and safety. *Phys Sportsmed* 38:171–179, 2010.

50. Bergstrom, J., Hermansen, L., Hultman, E., and Saltin, B. Diet, muscle glycogen and physical performance. *Acta Physiol Scand* 71:140–150, 1967.

51. Sedlock, D. A. The latest on carbohydrate loading: A practical approach. *Curr Sports Med Rep* 7:209–213, 2008.

52. Spaccarotella, K. J., and Andzel, W. D. Building a beverage for recovery from endurance activity: A review. *J Strength Cond Res* 25:3198–3204, 2011.

53. Pritchett, K., and Pritchett, R. Chocolate milk: A post-exercise recovery beverage for endurance sports. *Med Sport Sci* 59: 127–134, 2012.

54. Howarth, K. R., Moreau, N. A., Phillips, S. M., and Gibala, M. J. Coingestion of protein with carbohydrate during recovery from endurance exercise stimulates skeletal muscle protein synthesis in humans. *J Appl Physiol* 106:1394–1402, 2009.

55. Peternelj, T. T., and Coombes, J. S. Antioxidant supplementation during exercise training: Beneficial or detrimental? *Sports Med* 41:1043–1069, 2011.

56. Williams, M. H. Dietary supplements and sports performance: Minerals. *J Internat Soc Sport Nutr* 2:43–49, 2005.

57. Di Luigi, L. Supplements and the endocrine system in athletes. *Clin Sports Med* 27:131–151, 2008.

58. Nissen, S. L., and Sharp R. L. Effect of dietary supplements on lean mass and strength gains with resistance exercise: A meta-analysis. *J Appl Physiol* 94:651–659, 2003.

59. van Loon, L. J. Role of dietary protein in post-exercise muscle reconditioning. *Nestle Nutr Inst Workshop Ser* 75:73–83, 2013.

60. Birzniece, V., Nelson, A. E., and Ho, K. K. Growth hormone and physical performance. *Trends Endocrinol Metab* 22:171–178, 2011.

61. Kanaley, J. A. Growth hormone, arginine and exercise. *Curr Opin Clin Nutr Metab Care* 11:50–54, 2008.

62. Chromiak, J. A., and Antonio, J. Use of amino acids as growth hormone-releasing agents by athletes. *Nutrition* 18:657–661, 2002.

63. Zajac, A., Poprzecki, S., Zebrowska, A., et al. Arginine and ornithine supplementation increases growth hormone and insulin-like growth factor-1 serum levels after heavy-resistance exercise in strength-trained athletes. *J Strength Cond Res* 24:1082–1090, 2010.

64. Van Amsterdam, J., Opperhuizen, A., and Hartgens, F. Adverse health effects of anabolic-androgenic steroids. *Regul Toxicol Pharmacol* 57:117–123, 2010.

65. Brown, G. A., Vukovich, M., and King, D. S. Testosterone prohormone supplements. *Med Sci Sports Exerc* 38:1451–1461, 2006.

66. Rowlands, D. S., and Thomson, J. S. Effects of beta-hydroxy-beta-methylbutyrate supplementation during resistance training on strength, body composition, and muscle damage in trained and untrained young men: A meta-analysis. *J Strength Cond Res* 23:836–846, 2009.

67. Cooper, R., Naclerio, F., Allgrove, J., and Jimenez, A. Creatine supplementation with specific view to exercise/sports performance: An update. *J Int Soc Sports Nutr* 9:33, 2012.

68. Kim, H. J., Kim, C. K., Carpentier, A., and Poortmans, J. R. Studies on the safety of creatine supplementation. *Amino Acids* 40:1409–1418, 2011.

69. Harris, R. C., and Stellingwerff, T. Effect of β-alanine supplementation on high-intensity exercise performance. *Nestle Nutr Inst Workshop Ser* 76:61–71, 2013.

70. Quesnele, J. J., Laframboise, M. A., Wong, J. J., et al. The effects of beta-alanine supplementation on performance: a systematic review of the literature. *Int J Sport Nutr Exerc Metab* 24:14–27, 2014.

71. Burke, L. M. Practical considerations for bicarbonate loading and sports performance. *Nestle Nutr Inst Workshop Ser* 75: 15–26, 2013.

72. Howatson, G., Hoad, M., Goodall, S., et al. Exercise-induced muscle damage is reduced in resistance-trained males by branched chain amino acids: A randomized, double-blind, placebo controlled study. *J Int Soc Sports Nutr* 9:20, 2012.

73. Fisher, J. W. Landmark advances in the development of erythropoietin. *Exp Biol Med* 235: 1398–1411, 2010.

74. Miyake, T., Kung, C. K.-H., and Goldwasser, E. Purification of human erythropoietin. *J Biol Chem* 252:5558–5564, 1977.

75. Eschbach, J. W., Egrie, J. C., Downing, M. R., et al. Correction of the anemia of end stage renal disease with recombinant human erythropoietin. Results of a combined phase I and II clinical trial. *N Engl J Med* 316:73–78, 1987.

76. Noakes, T. D. Tainted glory—Doping and athletic performance. *N Engl J Med* 351:847–849, 2004.

77. Jeukendrup, A. E., and Randell, R. Fat burners: Nutrition supplements that increase fat metabolism. *Obes Rev* 12:841–851, 2011.

78. Clegg, M. E. Medium-chain triglycerides are advantageous in promoting weight loss although not beneficial to exercise performance. *Int J Food Sci Nutr* 61:653–679, 2010.

79. Pesta, D. H., Angadi, S. S., Burtscher, M., and Roberts, C. K. The effects of caffeine, nicotine, ethanol, and tetrahydrocannabinol on exercise performance. *Nutr Metab (Lond)* 10:71, 2013.

Chapter 14

1. Committee to Reexamine IOM Pregnancy Weight Guidelines, Institute of Medicine, National Research Council. *Weight Gain During Pregnancy: Reexamining the Guidelines*. Washington, DC: National Academies Press, 2009.

2. Procter, S. B., and Campbell, C. G. Position of the Academy of Nutrition and Dietetics: Nutrition and lifestyle for a healthy pregnancy outcome. *J Acad Nutr Diet* 114: 1099–1103, 2014.

3. Iacovidou, N., Varsami, M., and Syggellou, A. Neonatal outcome of preterm delivery. *Ann NY Acad Sci* 1205:130–134, 2010.

4. American College of Obstetrics and Gynecology, Committee Opinion. *Weight Gain During Pregnancy* (no. 458 2013). Available online at http://www.acog.org/Resources-And-Publications/Committee-Opinions/Committee-on-Obstetric-Practice/Weight-Gain-During-Pregnancy. Accessed March 22, 2015.

5. Al-Hinai, M., Al-Muqbali, M., Al-Moqbali, et al. Effects of pre-pregnancy body mass index and gestational weight gain on low birth weight in Omani infants: A case-control study. *Sultan Qaboos Univ Med J* 13:386–391, 2013.

6. Denison, F. C., Norwood, P., Bhattacharya, S., et al. Association between maternal body mass index during pregnancy, short-term morbidity, and increased health service costs: A population-based study. *BJOG* 121:72–81, 2014.

7. Li, N., Liu, E., Guo, J., et al. Maternal prepregnancy body mass index and gestational weight gain on pregnancy outcomes. *PLoS One* 8:e82310, 2013.

8. Rasmussen, S. A., Chu, S. Y., Kim, S. Y, et al. Maternal obesity and risk of neural tube defects: A metaanalysis. *Am J Obstet Gynecol* 198:611–619, 2008.

9. Poston, L. Gestational weight gain: Influences on the long-term health of the child. *Curr Opin Clin Nutr Metab Care* 15:252–257, 2012.

10. Galliano, D., and Bellver, J. Female obesity: Short- and long-term consequences on the offspring. *Gynecol Endocrinol* 29:626–631, 2013.

11. U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans*. Available online at http://www.health.gov/paguidelines. Accessed March 23, 2015.

12. Einarson, T. R., Piwko, C., and Koren, G. Prevalence of nausea and vomiting of pregnancy in the USA: A meta analysis. *J Popul Ther Clin Pharmacol* 20:e163–e170, 2013.

13. Maltepe, C., and Koren, G. The management of nausea and vomiting of pregnancy and hyperemesis gravidarum—A 2013 update. *J Popul Ther Clin Pharmacol* 20:e184–e192, 2013.

14. National Center for Health Statistics, Centers for Disease Control and Prevention. *Infant Health*. Available online at http://www.cdc.gov/nchs/fastats/infant-health.htm. Accessed March 24, 2015.

15. Lo, J. O., Mission, J. F., and Caughey, A. B. Hypertensive disease of pregnancy and maternal mortality. *Curr Opin Obstet Gynecol* 25:124–132, 2013.

16. Berg, C. J., Callahan, W. M., Syverson, C., and Henderson, Z. Pregnancy-related mortality in the United States 1998–2005. *Obstet Gynecol* 166:1302–1309, 2010.

17. Mustafa, R., Ahmed, S., Gupta, A., and Venuto, R. C. A comprehensive review of hypertension in pregnancy. *J Pregnancy* 2012:105918, 2012.

18. Task Force on Hypertension in Pregnancy, American College of Obstetricians and Gynecologists. Hypertension in pregnancy. Report of the American College of Obstetricians and Gynecologists' Task Force on Hypertension in Pregnancy. *Obstet Gynecol* 122:1122–1131, 2013.

19. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes Water, Potassium, Sodium, Chloride, and Sulfate.* Washington, DC: National Academies Press, 2004.

20. Thangaratinam, S., Langenveld, J., Mol, B. W., and Khan, K. S. Prediction and primary prevention of pre-eclampsia. *Best Pract Res Clin Obstet Gynaecol* 25:419–433, 2011.

21. DeSisto, C. L., Kim, S. Y., and Sharma, A. J. Prevalence estimates of gestational diabetes mellitus in the United States, Pregnancy Risk Assessment Monitoring System (PRAMS), 2007–2010. *Prev Chronic Dis* 11:E104, 2014.

22. Centers for Disease Control and Prevention. *National Diabetes Statistic Report, 2014*. Available online at http://www.cdc.gov/diabetes/pubs/statsreport14/national-diabetes-report-web.pdf. Accessed March 22, 2015.

23. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)*. Washington, DC: National Academies Press, 2005.

24. Scholtz, S. A., Colombo, J., and Carlson, S. E. Clinical overview of effects of dietary long-chain polyunsaturated fatty acids during the perinatal period. *Nestle Nutr Inst Workshop Ser* 77:145–154, 2013.

25. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Calcium and Vitamin D.* Washington, DC: National Academies Press, 2011.

26. Kovacs, C. S. Calcium and bone metabolism disorders during pregnancy and lactation. *Endocrinol Metab Clin North Am* 40:795–826, 2011.

27. Yumusakhuylu, Y., Turgut, S. T., Icagasioglu, A., et al. Bone mineral changes during pregnancy and lactation. *Gynecol Endocrinol* 29:763–766, 2013.

28. Vitamin D insufficiency in pregnant and nonpregnant women of childbearing age in the United States (Committee Opinion no. 495).*Obstet Gynecol* 111:197–198, 2011.

29. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. Washington, DC: National Academies Press, 2000.

30. Williams, J., Mai, C. T., Mulinare, J., et al. Updated estimates of neural tube defects prevented by mandatory folic acid fortification—United States, 1995–2011. *MMWR Morb Mortal Wkly Rep* 64:1–5, 2015.

31. Crider, K. S., Bailey, L. B., and Berry, R. J. Folic acid food fortification—Its history, effect, concerns, and future directions. *Nutrients* 3:370–384, 2011.

32. Scholl, T. O., and Johnson, W. G. Folic acid: Influence on the outcome of pregnancy. *Am J Clin Nutr* 71(suppl):1295S–1303S, 2000.

33. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B-6, Folate, Vitamin B-12, Pantothenic Acid, Biotin, and Choline*. Washington, DC: National Academies Press, 1998.

34. Smithells, R. W., Sheppard, S., and Schorah, C. J. Vitamin deficiencies and neural tube defects. *Arch Dis Child* 51: 944–949, 1976.

35. Smithells, R. W., Sheppard, S., Schorah, C. J., et al. Possible prevention of neural tube defects by periconceptional vitamin supplementation. *Lancet* 1:339–340, 1980.

36. MRC Vitamin Study Research Group. Prevention of neural tube defects: Results of the MRC vitamin study. *Lancet* 338:131–137, 1991.

37. Czeizel, A. E., and Dudás, I. Prevention of the first occurrence of neural-tube defects by periconceptional vitamin supplementation. *N Engl J Med* 327:1832–1835, 1992.

38. Czeizel, A. E. Folic acid and the prevention of neural tube defects. *J Pediatr Gastroenterol Nutr* 20:4–16, 1995.

39. Werler, M. M., Shapiro, S., and Mitchell, A. A. Periconceptional folic acid exposure and the risk of occurrent neural tube defects. *JAMA* 269:1257–1261, 1993.

40. Daly, S., Mills, J. L., Molloy, A. M., et al. Minimum effective dose of folic acid for food fortification to prevent neural-tube defects. *Lancet* 350:1666–1669, 1997.

41. Use of folic acid-containing supplements among women of childbearing age—United States, 1997. *MMWR Morb Mortal Wkly Rep* 47:131–134, 1998. Available online at cdc.gov/mmwr/preview/mmwrhtml/00051435.htm. Accessed March 30, 2015.

42. Pepper, M. R., and Black, M. M. B12 in fetal development. *Semin Cell Dev Biol* 22:619–623, 2011.

43. Chaffee, B. W., and King, J. C. Effect of zinc supplementation on pregnancy and infant outcomes: A systematic review. *Paediatr Perinat Epidemiol* 26 Suppl 1:118–137, 2012.

44. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. Washington, DC: National Academies Press, 2001.

45. Cao, C., and O'Brien, K. O. Pregnancy and iron homeostasis: An update. *Nutr Rev* 71:35–51, 2013.

46. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*, 5th ed. Arlington, VA: American Psychiatric Publishing, 2013.

47. Mills, M. E. Craving more than food: The implications of pica in pregnancy. *Nurs Women's Health* 11:266–273, 2007.

48. McArthur, J. O., Tang, H., Petocz, P., and Samman, S. Biological variability and impact of oral contraceptives on vitamins B(6), B(12) and folate status in women of reproductive age. *Nutrients* 5:3634–3645, 2013.

49. Fall, C. H. Fetal programming and the risk of noncommunicable disease. *Indian J Pediatr* 80(suppl 1):S13–S20, 2013.

50. Desai, M., Beall, M., and Ross, M. G. Developmental origins of obesity: Programmed adipogenesis. *Curr Diab Rep* 13:27–33, 2013.

51. Roseboom, T., de Rooij, S., and Painter, R. The Dutch famine and its long-term consequences for adult health. *Early Hum Dev* 82:485–491, 2006.

52. Centers for Disease Control and Prevention. *Pediatric and Pregnancy Nutrition Surveillance System, Health Indicators*. Available online at www.cdc.gov/pednss/what_is/pnss_health_indicators.htm#Maternal%20Health%20Indicators. Accessed March 23, 2015.

53. National Center for Health Statistics, Centers for Disease Control and Prevention. *Teen Births*. Available online at http://www.cdc.gov/nchs/fastats/teenbrth.htm. Accessed March 23, 2015.

54. Casanueva, E., Roselló-Soberón, M. E., and De-Regil, L. M. Adolescents with adequate birth weight newborns diminish energy expenditure and cease growth. *J Nutr* 136:2498–2501, 2006.

55. Carolan, M. Maternal age ≥45 years and maternal and perinatal outcomes: A review of the evidence. *Midwifery* 29:479–489, 2013.

56. National Down Syndrome Congress. *Down Syndrome Facts*. Available online at http://ndsccenter.org/worpsite/wp-content/uploads/2012/09/Down-Syndrome-Facts.pdf. Accessed March 24, 2015.

57. de Graaf, J. P., Steegers, E. A., and Bonsel, G. J. Inequalities in perinatal and maternal health. *Curr Opin Obstet Gynecol* 25:98–108, 2013.

58. USDA Food and Nutrition Service. *How WIC Helps*. Available online at http://www.fns.usda.gov/wic/about-wic-how-wic-helps. Accessed March 23, 2015.

59. Moore, K., and Persaud, T. *The Developing Human*, 5th ed. Philadelphia: W. B. Saunders Company, 1993.

60. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.

61. U.S. Food and Drug Administration. *Fish: What Pregnant Women and Parents Should Know (Draft Updated Advice by FDA and EPA)*, June 2014. Available online at http://www.fda.gov/Food/FoodborneIllnessContaminants/Metals/ucm393070.htm. Accessed April 17, 2015.

62. Mayo Clinic Staff. *Pregnancy Nutrition: Foods to Avoid During Pregnancy*. Available online at http://www.mayoclinic.org/healthy-living/pregnancy-week-by-week/in-depth/pregnancy-nutrition/art-20043844. Accessed March 15, 2014.

63. American College of Obstetricians and Gynecologists. ACOG Committee Opinion No. 462: Moderate caffeine consumption during pregnancy. *Obstet Gynecol* 116(2 pt 1): 467–468, 2010.

64. Brent, R. L., Christian, M. S., and Diener, R. M. Evaluation of the reproductive and developmental risks of caffeine. *Birth Defects Res B Dev Reprod Toxicol* 92:152–187, 2011.

65. Lamont, R. F., Sobel, J., Mazaki-Tovi, S., et al. *Listeriosis* in human pregnancy: A systematic review. *J Perinat Med* 39: 227–236, 2011.

66. U.S. Food and Drug Administration, Center for Food Safety and Nutrition. *Bad Bug Book: Foodborne Pathogenic Microorganisms and Natural Toxins Handbook*, 2nd ed. Available online at http://www.fda.gov/food/foodborneillnesscontaminants/causesofillnessbadbugbook/default.htm. Accessed April 5, 2015.

67. Goodlett, C. R., and Horn, K. H. Mechanisms of alcohol-induced damage to the developing nervous system. *Alcohol Res Health* 25:175–184, 2001.

68. Riley, E. P., Infante, M. A., and Warren, K. R. Fetal alcohol spectrum disorders: An overview. *Neuropsychol Rev* 99:298–302, 2011.

69. May, P. A., Baete, A., Russo, J., et al. Prevalence and characteristics of fetal alcohol spectrum disorders. *Pediatrics* 134:855–866, 2014.

70. Rogers, J. M. Tobacco and pregnancy: Overview of exposures and effects. *Birth Defects Res C Embryo Today* 84:1–15, 2008.

71. Clifford, A., Lang, L., and Chen, R. Effects of maternal cigarette smoking during pregnancy on cognitive parameters of children and young adults: A literature review. *Neurotoxicol Teratol* 34:560–570, 2012.

72. Xiao, D., Huang, X., Yang, S., and Zhang, L. Direct effects of nicotine on contractility of the uterine artery in pregnancy. *J Pharmacol Exp Ther* 322:180–185, 2007.

73. Task Force on Sudden Infant Death Syndrome, Moon, R.Y. SIDS and other sleep-related infant deaths: Expansion of recommendations for a safe infant sleeping environment. *Pediatrics* 128:e1341–e1367, 2011.

74. Burke, H., Leonardi-Bee, J., Hashim, A., et al. Prenatal and passive smoke exposure and incidence of asthma and wheeze: Systematic review and meta-analysis. *Pediatrics* 129:735–744, 2012.

75. Behnke, M., and Smith, V. C.; Committee on Substance Abuse; Committee on Fetus and Newborn. Prenatal substance abuse: Short- and long-term effects on the exposed fetus. *Pediatrics* 131:e1009–e1024, 2013.

76. Schempf, A. H. Illicit drug use and neonatal outcomes: A critical review. *Obstet Gynecol Surv* 62:749–757, 2007.

77. Fajemirokun-Odudeyi, O., and Lindow, S. W. Obstetric implications of cocaine use in pregnancy: A literature review. *Eur J Obstet Gynecol Reprod Biol* 112:2–8, 2004.

78. Innis, S. M. Impact of maternal diet on human milk composition and neurological development of infants. *Am J Clin Nutr* 99:734S–741S, 2014.

79. Allen, L. H. B vitamins in breast milk: Relative importance of maternal status and intake, and effects on infant status and function. *Adv Nutr* 3:362–369, 2012.

80. Ballard, O., and Morrow, A. L. Human milk composition: Nutrients and bioactive factors. *Pediatr Clin North Am* 60: 49–74, 2013.

81. Simmer, K., Patole, S. K., and Rao, S. C. Long-chain polyunsaturated fatty acid supplementation in infants born at term. *Cochrane Database Syst Rev*12:CD000376, 2011.

82. Guesnet, P., and Alessandri, J. M. Docosahexaenoic acid (DHA) and the developing central nervous system (CNS): Implications for dietary recommendations. *Biochimie* 93:7–12, 2011.

83. Tai, E. K., Wang, X. B., and Chen, Z. Y. An update on adding docosahexaenoic acid (DHA) and arachidonic acid (AA) to baby formula. *Food Funct* 4:1767–1775, 2013.

84. Lapillonne, A., Groh-Wargo, S., Gonzalez, C. H., and Uauy, R. Lipid needs of preterm infants: Updated recommendations. *J Pediatr* 162(3 suppl):S37–S47, 2013.

85. Hoffman, D. R., Boettcher, J. A., and Diersen-Schade, D. A. Toward optimizing vision and cognition in term infants by dietary docosahexaenoic and arachidonic acid supplementation: A review of randomized controlled trials. *Prostaglandins Leukot Essent Fatty Acids* 81:151–158, 2009.

86. Birch, E. E., Garfield, S., Castañeda, Y., et al. Visual acuity and cognitive outcomes at 4 years of age in a double-blind, randomized trial of long-chain polyunsaturated fatty acid-supplemented infant formula. *Early Hum Dev* 83: 279–284, 2007.

87. Qawasmi, A., Landeros-Weisenberger, A., Leckman, J. F., and Bloch, M. H. Meta-analysis of long-chain polyunsaturated fatty acid supplementation of formula and infant cognition. *Pediatrics* 129:1141–1149, 2012.

88. Gale, C. R., Marriott, L. D., Martyn, C. N., and Group for Southampton Women's Survey Study. Breastfeeding, the use of docosahexaenoic acid-fortified formulas in infancy and neuropsychological function in childhood. *Arch Dis Child* 95:174–179, 2009.

89. Makrides, M., Smithers, L. G., and Gibson, R. A. Role of long-chain polyunsaturated fatty acids in neurodevelopment and growth. *Nestle Nutr Workshop Ser Pediatr Program* 65:123–133, 2010.

90. Wagner, C. L., and Greer, F. R.; American Academy of Pediatrics Section on Breast-Feeding; American Academy of Pediatrics Committee on Nutrition. Prevention of rickets and vitamin D deficiency in infants, children, and adolescents. *Pediatrics* 122:1142–1152, 2008.

91. American Academy of Pediatrics *Where we stand: Administration of vitamin K*. Available online at https://www.healthychildren.org/English/ages-stages/prenatal/delivery-beyond/Pages/Where-We-Stand-Administration-of-Vitamin-K.aspx Accessed August 11, 2015.

92. National Center for Health Statistics, Centers for Disease Control and Prevention. *CDC Growth Charts: United States, Advance Data, No. 314*, June 8, 2000 (revised). Available online at http://www.cdc.gov/growthcharts. Accessed March 25, 2015.

93. Centers for Disease Control and Prevention. *Growth Charts: WHO Growth Standards Are Recommended for Use in the U.S. for Infants and Children 0 to 2 Years of Age*. Available online at http://www.cdc.gov/growthcharts/who_charts.htm#The%20WHO%20Growth%20Charts. Accessed April 5, 2015.

94. Adair, L. S. Long-term consequences of nutrition and growth in early childhood and possible preventive interventions. *Nestle Nutr Inst Workshop Ser* 78:111–120, 2014.

95. Victora, C. G., Adair, L., Fall, C., et al.; Maternal and Child Undernutrition Study Group. Maternal and child undernutrition: Consequences for adult health and human capital. *Lancet* 371:340–357, 2008.

96. Lessen, R., and Kavanagh, K. Position of the Academy of Nutrition and Dietetics: Promoting and supporting breastfeeding. *J Acad Nutr Diet* 115:444–449, 2015.

97. American Academy of Pediatrics, Section on Breast-Feeding. *Executive Summary: Breastfeeding and the Use of Human Milk*. Available online at http://www2.aap.org/breastfeeding/files/pdf/Breastfeeding2012ExecSum.pdf. Accessed March 25, 2015.

98. World Health Organization. *Infant and Young Child Feeding* (WHO Fact Sheet no. 342), February 2014. Available online at http://www.who.int/mediacentre/factsheets/fs342/en. Accessed March 25, 2015.

Chapter 15

1. Hiza, H. A. B., Guenther, P. M., and Rihane, C. I. USDA Center for Nutrition Policy and Promotion. Diet quality of children 2–17 years as measured by the Healthy Eating Index–2010. *Nutrition Insight* 52, July 2013.

2. Ogata, B. N., and Hayes, D. Position of the Academy of Nutrition and Dietetics: Nutrition guidance for healthy children ages 2 to 11 years. *J Acad Nutr Diet* 114:1257–1276, 2014.

3. Centers for Disease Control and Prevention. *Nutrition and the Health of Young People*. Available online at http://www.cdc.gov/healthyyouth/nutrition/facts.htm. Accessed March 2, 2015.

4. Orlet Fisher, J., Rolls, B. J., and Birch, L. L. Children's bite size and intake of an entree are greater with large portions than with age-appropriate or self-selected portions. *Am J Clin Nutr* 77:1164–1170, 2003.

5. Duffey, K. J., and Popkin, B. M. Causes of increased energy intake among children in the U.S., 1977–2010. *Am J Prev Med* 44:e1–e8, 2013.

6. Mancino, L., Todd, J. E., Guthrie, J., and Lin, B.-H.; U.S. Department of Agriculture Economic Research Service. *How Food Away from Home Affects Children's Diet Quality* (Economic Research Service Report no. 104), October 2010. Available online at http://www.ers.usda.gov/media/136261/err104_3_.pdf. Accessed March 29, 2015.

7. Centers for Disease Control and Prevention. *Childhood Obesity Facts.* Available online at http://www.cdc.gov/healthyyouth/obesity/facts.htm. Accessed March 29, 2015.

8. Ogden, C. L. Carroll, M. D., Kit, B. K., and Flegal, K. M. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA* 311:806–814, 2014.

9. American Academy of Child and Adolescent Psychiatry. Obesity in children and teens (*Facts for Families*, no. 79), March 2011. Available online at http://www.aacap.org/App_Themes/AACAP/docs/facts_for_families/79_obesity_in_children_and_teens.pdf. Accessed March 29, 2015.

10. Centers for Disease Control and Prevention. *National Diabetes Statistics Report: Estimates of Diabetes and Its Burden in the United States, 2014*. Available online at http://www.cdc.gov/diabetes/pubs/statsreport14/national-diabetes-report-web.pdf. Accessed March 28, 2015.

11. Ervin, R.B. and Ogden, C.L. Trends in Intake of Energy and Macronutrients in Children and Adolescents from 1999–2000 through 2009–2010. *NCHS Data Brief* Feb (113):1–8, 2013.

12. Centers for Disease Control and Prevention. *Facts about Physical Activity*. Available online at http://www.cdc.gov/physicalactivity/data/facts.html. Accessed March 28, 2015.

13. National Institutes of Health, National Heart, Lung, and Blood Institute. *Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents*. Available online at http://www.nhlbi.nih.gov/health-pro/guidelines/current/cardiovascular-health-pediatric-guidelines. Accessed March 28, 2015.

14. Thompson, M., Dana, T., Bougatsos C., et al. Screening for hypertension in children and adolescents to prevent cardiovascular disease. *Pediatrics* 131:490–525, 2013.

15. U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans*, 2015–2020, 8th ed. Available online at http://health.gov/dietaryguidelines/2015/guidelines/. Accessed January 11, 2016.

16. Centers for Disease Control and Prevention. *Growth Charts: WHO Growth Standards Are Recommended for Use in the U.S. for Infants and Children 0 to 2 Years of Age*. Available online at http://www.cdc.gov/growthcharts/who_charts.htm#The%20WHO%20Growth%20Charts. Accessed March 30, 2015.

17. Centers for Disease Control and Prevention. *CDC Growth Charts*. Available online at http://www.cdc.gov/growthcharts. Accessed April 6, 2015.

18. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Protein and Amino Acids*. Washington, DC: National Academies Press, 2002.

19. U.S. Food and Drug Administration. *Nutrition Labeling; Questions L1 through L153*, January 2013. Available online at http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm064904.htm#kidlabel. Accessed April 6, 2015.

20. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate*. Washington, DC: National Academies Press, 2004.

21. Butte, N. F., Fox, M. K., Briefel, R. R., et al. Nutrient intakes of US infants, toddlers, and preschoolers meet or exceed dietary reference intakes. *J Am Diet Assoc* 110(12 suppl):S27–S37, 2010.

22. Fox, M. K., Condon, E., Briefel, R. R., et al. Food consumption patterns of young preschoolers: Are they starting off on the right path? *J Am Diet Assoc* 110(12 suppl):S52–S59, 2010.

23. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Calcium and Vitamin D*. Washington, DC: National Academies Press, 2011.

24. Risk Factor Monitoring and Methods Branch, National Cancer Institute. *Sources of Beverage Intakes among the US Population, 2005–06*. Available online at http://riskfactor.cancer.gov/diet/foodsources/beverages. Accessed March 29, 2015.

25. Rovner, A. J., and O'Brien, K. O. Hypovitaminosis D among healthy children in the United States: A review of the current evidence. *Arch Pediatr Adolesc Med* 162:513–519, 2008.

26. U.S. Department of Agriculture, Agricultural Research Service. Table 1: Nutrient intakes from food and beverages: Mean amounts consumed per individual by gender and age, in the United States, 2011–2012. *What We Eat in America* (NHANES 2011–2012). Available online at http://www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/1112/Table_1_NIN_GEN_11.pdf. Accessed April 6, 2015.

27. Centers for Diseases Control and Prevention. *Nutrition for Everyone. Iron and Iron Deficiency.* Available online at http://www.cdc.gov/nutrition/everyone/basics/vitamins/iron.html. Accessed March 29, 2015.

28. Centers for Disease Control and Prevention. *FastStats: Anemia or Iron Deficiency*. Available online at http://www.cdc.gov/nchs/fastats/anemia.htm. Accessed February 23, 2015.

29. Centers for Disease Control and Prevention. *IMMPaCt—International Micronutrient Malnutrition Prevention and Control Program, Micronutrient Facts.* Available online at http://www.cdc.gov/immpact/micronutrients/index.html. Accessed March 29, 2015.

30. U.S. Food and Drug Administration. *Guidance for Industry: Iron-Containing Supplements and Drugs: Label Warning Statements and Small Entity Compliance Guide*, October 17, 2003. Available online at http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/DietarySupplements/ucm073014.htm. Accessed February 23, 2015.

31. Fisher, J. O., Liu, J., Birch, L. L., and Rolls, B. J. Effects of portion size and energy density on young children's intake at a meal. *Am J Clin Nutr* 86:174–179, 2007.

32. Food and Nutrition Service, U.S. Department of Agriculture. *Feeding Solid Foods*. Available online at http://www.fns.usda.gov/sites/default/files/feedinginfants-ch7.pdf. Accessed March 29, 2015.

33. Rajakumar, K. Vitamin D, cod-liver oil, sunlight, and rickets: A historical perspective. *Pediatrics* 112:e132–e135, 2003.

34. Holick, M. F. The vitamin D deficiency pandemic: A forgotten hormone important for health. *Public Health Rev* 32:267–283, 2010.

35. Rajakumar, K., Greenspan, S. L., Thomas, S. B., and Holick, M. F. Solar ultraviolet radiation and vitamin D: A historical perspective. *Am J Public Health* 97:1746–1754, 2007.

36. Veick, M. T. A history of rickets in the United States. *Am J Clin Nutr* 20:1234–1244, 1967.

37. American Academy of Pediatrics. The use and misuse of fruit juice in pediatrics. *Pediatrics* 107:1210–1213, 2001.

38. Food and Nutrition Service, U.S. Department of Agriculture. *National School Lunch Program.* Available online at http://www.fns.usda.gov/cnd/Lunch/AboutLunch/NSLPFactSheet.pdf.Accessed March 29, 2015.

39. Food and Nutrition Service, U.S. Department of Agriculture. National School Lunch and School Breakfast Program: Nutrition standards for all foods sold in school as required by the Healthy, Hunger-Free Kids Act of 2010. Interim Final Rule. *Federal Register* 78(125):39068–39120, June 28, 2013.

40. Schwartz, M. B., Henderson, K. E., Read, M., et al. New school meal regulations increase fruit consumption and do not increase total plate waste. *Child Obes* 11:242–247, 2015.

41. American Academy of Pediatrics. *What You Need to Know about the New Guidelines for the Diagnosis and Management of Food Allergy in the U.S.* Available online at http://www2.aap.org/sections/allergy/allergy_guidelines_final_1.pdf. Accessed March 29, 2015.

42. Fleischer, D. M., Spergel, J. M., Assa'ad, A. H., and Pongracic, J. A. Primary prevention of allergic disease through nutritional interventions. *J Allergy Clin Immunol Pract* 1:29–36, 2013.

43. de Silva, D., Geromi, M., Halken, S., et al.; EAACI Food Allergy and Anaphylaxis Guidelines Group. Primary prevention of food allergy in children and adults: Systematic review. *Allergy* 69:581–589, 2014.

44. Marshall, T. A., Levy, S. M., Broffitt, B., et al. Dental caries and beverage consumption in young children. *Pediatrics* 112: e184–e191, 2003.

45. Centers for Disease Control and Prevention. *Attention Deficit/Hyperactivity Disorder: Data and Statistics*. Available online at http://www.cdc.gov/ncbddd/adhd/data.html. Accessed March 29, 2015.

46. Millichap, J. G., and Yee, M. M. The diet factor in attention-deficit/hyperactivity disorder. *Pediatrics* 129:330–337, 2012.

47. Centers for Disease Control and Prevention. Blood lead levels in children aged 1–5 years—United States, 1999–2010. *Morb Mortal Wkly Rep* 62:245–248**,** 2013.

48. Centers for Disease Control and Prevention. Ten great public health achievements—United States, 2001–2010. *Morb Mortal Wkly Rep* 60:619–623, 2011.

49. Centers for Disease Control and Prevention. *Blood Lead Level.* Available online at http://cfpub.epa.gov/eroe/index.cfm?fuseaction=detail.viewPDF&ch=49&lShowInd=0&subtop=208&lv=list.listByChapter&r=224030. Accessed May 23, 2015.

50. Centers for Disease Control and Prevention. *Childhood Obesity Facts.* Available online at http://www.cdc.gov/healthyyouth/obesity/facts.htm. Accessed March 30, 2015.

51. Coon, K. A., and Tucker, K. L. Television and children's consumption patterns. A review of the literature. *Minerva Pediatr* 54:423–436, 2002.

52. Batada, A., Seitz, M., Woxan, M., et al. Nine out of ten food advertisements shown during Saturday morning children's television programming are for food high in fat, sodium, or added sugars, or low in nutrients. *J Am Diet Assoc* 108:673–678, 2008.

53. Costa, S. M., Horta, P. M., and dos Santos, L. C. Food advertising and television exposure: Influence on eating behavior and nutritional status of children and adolescents. *Arch Latinoam Nutr* 62:53–59, 2012.

54. Braithwaite, I., Stewart, A. W., Hancox, R. J., et al.; ISAAC Phase Three Study Group. The worldwide association between television viewing and obesity in children and adolescents: Cross sectional study. *PLoS One* 8:e74263, 2013.

55. Food and Nutrition Board, Institute of Medicine. *Preventing Childhood Obesity: Health in the Balance*. Washington, DC: National Academies Press, 2005.

56. U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans*. Available online at http://www.health.gov/paguidelines/ pdf/paguide.pdf. Accessed March 29, 2015.

57. Barlow, S. E.; Expert Committee. Expert Committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: Summary report. *Pediatrics* 120(suppl 4):S164–S192, 2007.

58. Centers for Disease Control and Prevention. *Making Physical Activity a Part of a Child's Life*. Available online at http://www.cdc.gov/physicalactivity/everyone/getactive/children.html. Accessed March 30, 2015.

59. Yermachenko, A., and Dvornyk, V. Nongenetic determinants of age at menarche: A systematic review. *Biomed Res Int* 2014:371583, 2014.

60. Forbes, G. B. Body composition. In *Present Knowledge in Nutrition*, 6th ed. M. L. Brown, Ed. Washington, DC: International Life Sciences Institute–Nutrition Foundation, 1990.

61. Sayers, A., Fraser, W. D., Lawlor, D. A., and Tobias, J. H. 25-Hydroxyvitamin-D3 levels are positively related to subsequent cortical bone development in childhood: Findings from a large prospective cohort study. *Osteoporos Int* 23:2117–2128, 2012.

62. Turer, C. B., Lin, H., and Flores, G. Prevalence of vitamin D deficiency among overweight and obese US children. *Pediatrics* 131:e152–e161, 2013.

63. Hoy, M. K., and Goldman, J. D. Calcium intake of the US population. *What We Eat in America* (NHANES 2009–2010; Dietary Data Brief no. 13), September 2014. Available online at http://www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/DBrief/13_calcium_intake_0910.pdf. Accessed March 30, 2015.

64. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc.* Washington, DC: National Academies Press, 2001.

65. Arsenault, J. E., and Brown, K. H. Zinc intake of US preschool children exceeds new dietary reference intakes. *Am J Clin Nutr* 78:1011–1017, 2003.

66. Centers for Disease Control and Prevention. Fruit and vegetable consumption among high school students—United States, 2010. *MMWR Morb Mortal Wkly Rep* 60:1583–1586, 2011.

67. Malik, V. S., Schulze, M. B., and Hu, F. B. Intake of sugar-sweetened beverages and weight gain: A systematic review. *Am J Clin Nutr* 84:274–288, 2006.

68. Coffey, S. Pepsi: Removing its sodas from schools worldwide. Available online at http://www.dailyfinance.com/2010/03/17/pepsi-removing-its-soda-from-schools-worldwide. Accessed March 30, 2015.

69. American Academy of Pediatrics. Expert Committee recommendations regarding the prevention, assessment, and treatment of child and adolescent overweight and obesity: Summary Report. *Pediatrics* 120:S164–S192, 2007.

70. Taber, D. R., Chriqui, J. F., Powell, L. M., et al. Banning all sugar-sweetened beverages in middle schools. *Arch Pediatr Adolesc Med* 166:256–262, 2012.

71. American Dietetic Association. Joint Position of ADA, Society for Nutrition Education and School Nutrition Association: Comprehensive school nutrition services. *J Am Diet Assoc* 110:1738–1749, 2010.

72. Sifferlin, A. Stricter school lunch standards lead to lighter kids. *Time,* April 11, 2013. Available online at http://healthland.time.com/2013/04/11/strict-school-meal-standards-lead-to-lighter-kids. Accessed April 3, 2015.

73. Taber, D. R., Chriqui, J. F., Powell, L., and Chaloupka, F. J. Association between state laws governing school meal nutrition content and student weight status: Implications for new USDA school meal standards. *JAMA Pediatr*167:513–519, 2013.

74. Dwyer, J. Defining nutritious breakfasts and their benefits. *J Acad Nutr Diet* 114:55S–57S, 2015.

75. Affenito, S. G., Thompson, D., Dorazio, A., et al. Ready-to-eat cereal consumption and the School Breakfast Program: Relationship to nutrient intake and weight. *J Sch Health* 83: 28–35, 2013.

76. Adolphus, K., Lawton, C. L., and Dye, L. The effects of breakfast on behavior and academic performance in children and adolescents. *Front Hum Neurosci* 7:425–429, 2013.

77. Vegetarian Resource Group. *How Many Teens Are Vegetarian? 2010 National Poll*. Available online at http://www.vrg.org/press/youth_poll_2010.php. Accessed March 30, 2015.

78. Rosen, D. S.; American Academy of Pediatrics Committee on Adolescence. Identification and management of eating disorders in children and adolescents. *Pediatrics* 12:1240–1253, 2010.

79. Rodriguiez, N. R., Dimarco, N. M., and Langley, S. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *J Am Diet Assoc* 109:509–527, 2009.

80. Brown, G. A., Vukovich, M., and King, D. S. Testosterone prohormone supplements. *Med Sci Sports Exerc* 38:1451–1461, 2006.

81. Cooper, R., Naclerio, F., Allgrove, J., and Jimenez, A. Creatine supplementation with specific view to exercise/sports performance: An update. *J Int Soc Sports Nutr* 9:33, 2012.

82. De Souza, M. J., Nattiv, A., Joy, E., et al.; Female Athlete Triad Coalition; American College of Sports Medicine; American Medical Society for Sports Medicine; American Bone Health Alliance. 2014 Female Athlete Triad Coalition consensus statement on treatment and return to play of the female athlete triad: 1st International Conference held in San Francisco, CA, May 2012, and 2nd International Conference held in Indianapolis, IN, May 2013. *Clin J Sport Med.* 24:96–119, 2014.

83. Mountjoy, M., Sundgot-Borgen, J., Burke, L., et al. The IOC consensus statement: Beyond the female athlete triad—Relative energy deficiency in sport (RED-S). *Br J Sports Med* 48:491–497, 2014.

84. Centers for Disease Control and Prevention. *Trends in Current Cigarette Smoking among High School Students and Adults, United States, 1965–2011*. Available online at http://www.cdc.gov/tobacco/data_statistics/tables/trends/cig_smoking/index.htm. Accessed March 30, 2015.

85. Facchini, M., Rozensztejn, R., and Gonzalez, C. Smoking and weight control behaviors. *Eat Weight Disord* 10:1–7, 2005.

86. McClure, J. B., Divine, G., Alexander, G., Tolsma, D., et al. A comparison of smokers' and nonsmokers' fruit and vegetable intake and relevant psychosocial factors. *Behav Med* 35:14–22, 2009.

87. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium and Carotenoids*. Washington, DC: National Academies Press, 2000.

88. Centers for Disease Control and Prevention. *Youth Risk Behavior Surveillance—United States, 2011*. Available online at http://www.cdc.gov/mmwr/preview/mmwrhtml/ss6104a1.htm. Accessed March 30, 2015.

89. National Institutes of Health, National Institutes of Alcohol Abuse and Alcoholism. *Heavy Episodic Alcohol Consumption*. Available online at http://www.collegedrinkingprevention.gov/niaaacollegematerials/taskforce/heavyepisodic_00.aspx. Accessed March 30, 2015.

Chapter 16

1. Anderson, R. M., and Weindruch, R. The caloric restriction paradigm: Implications for healthy human aging. *Am J Hum Biol* 24:101–106, 2012.

2. Speakman, J. R., and Mitchell, S. E. Caloric restriction. *Mol Aspects Med* 32:159–221, 2011.

3. McCay, C. M., Crowell, M. F., and Maynard, L. A. The effect of retarded growth upon the length of life and upon ultimate size. *J Nutr* 10:63–79, 1935.

4. Park, H. W. Longevity, aging, and caloric restriction: Clive Maine McCay and the construction of a multidisciplinary research program. *Hist Stud Nat Sci* 40:79–124, 2010.

5. Omodei, D., and Fontana, L. Calorie restriction and prevention of age-associated chronic disease. *FEBS Lett* 585:1537–1542, 2011.

6. Kemnitz, J. W. Calorie restriction and aging in nonhuman primates. *ILARJ* 52:66–77, 2011.

7. Mattison, J. A., Roth, G. S., Beasley, T. M., et al. Impact of caloric restriction on health and survival in rhesus monkeys from the NIA study. *Nature* 489:318–321, 2012.

8. Colman, R. J., Beasley, T. M., Kemnitz, J. W., et al. Caloric restriction reduces age-related and all-cause mortality in rhesus monkeys. *Nat Commun* 5:3557, 2014.

9. Willcox, B. J., Willcox, D. C., Todoriki, H., et al. Caloric restriction, the traditional Okinawan diet, and healthy aging: The diet of the world's longest-lived people and its potential impact on morbidity and life span. *Ann NY Acad Sci* 1114:434–455, 2007.

10. Willcox, D. C., Scapagnini, G., and Willcox, B. J. Healthy aging diets other than the Mediterranean: A focus on the Okinawan diet. *Mech Ageing Dev* 136–137:148–162, 2014.

11. Taormina, G., and Mirisola, M. G. Calorie restriction in mammals and simple model organisms. *Biomed Res Int* 2014:308690, 2014.

12. Ingram, D. K., and Roth, G. S. Calorie restriction mimetics: Can you have your cake and eat it, too? *Ageing Res Rev* 20C: 46–62, 2015.

13. Kochanek, K. D., Murphy, S. L., Xu, J., and Arias, E. Mortality in the United States, 2013. *NCHS Data Brief* Dec (178):1–8, 2014.

14. Administration on Aging, Administration for Community Living, U.S. Department of Health and Human Services. *A Profile of Older Americans 2014*. Available online at http://www.aoa.acl.gov/Aging_Statistics/Profile/2014/docs/2014-Profile.pdf. Accessed August 17, 2015.

15. Molla, M. T.; Centers for Disease Control and Prevention (CDC). Expected years of life free of chronic condition-induced activity limitations—United States, 1999–2008. *MMWR Surveill Summ* 62(suppl 3):87–92, 2013.

16. Fries, J. F. Aging, natural death, and the compression of morbidity. *N Engl J Med* 303:130–135, 1980.

17. Shen, J., and Tower, J. Programmed cell death and apoptosis in aging and life span regulation. *Discov Med* 8:223–226, 2009.

18. Dorner, B., Friedrich, E. K., and Posthauer, M. E. Position of the American Dietetic Association: Individualized nutrition approaches for older adults in health care communities. *J Am Diet Assoc* 110:1549–1553, 2010.

19. Grover, A. K., and Samson, S. E. Antioxidants and vision health: Facts and fiction. *Mol Cell Biochem* 388:173–183, 2014.

20. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B_6, Folate, Vitamin B_{12}, Pantothenic Acid, Biotin, and Choline.* Washington, DC: National Academies Press, 1998.

21. Bharucha, A. E., Dorn, S. D., Lembo, A., and Pressman, A.; American Gastroenterological Association. American Gastroenterological Association medical position statement on constipation. *Gastroenterology* 144:211–217, 2013.

22. Kohara, K. Sarcopenic obesity in aging population: Current status and future directions for research. *Endocrine* 45:15–25, 2014.

23. Ogden, C. L., Carroll, M. D., Kit, B. K., and Flegal, K. M. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA* 311:806–814, 2014.

24. Cetin, D. C., and Nasr, G. Obesity in the elderly: More complicated than you think. *Cleve Clin J Med* 81:51–61, 2014.

25. Gonnelli, S., Caffarelli, C., and Nuti, R. Obesity and fracture risk. *Clin Cases Miner Bone Metab* 11:9–14, 2014.

26. Cohn, S. H., Vartsky, D., Yasumura, S., et al. Compartmental body composition based on total-body nitrogen, potassium, and calcium. *Am J Physiol* 239:192–200, 1980.

27. Visser, W. E., Visser, T. J., and Peeters, R. P. Thyroid disorders in older adults. *Endocrinol Metab Clin North Am* 42:287–303, 2013.

28. Gurney, E. P., Nachtigall, M. J., Nachtigall, L. E., and Naftolin, F. The Women's Health Initiative trial and related studies: 10 years later: A clinician's view. *J Steroid Biochem Mol Biol* 142:4–11, 2014.

29. Sattler, F. R. Growth hormone in the aging male. *Best Pract Res Clin Endocrinol Metab* 27:541–555, 2013.

30. Samaras, N., Samaras, D., Frangos, E., et al. A review of age-related dehydroepiandrosterone decline and its association with well-known geriatric syndromes: Is treatment beneficial? *Rejuvenation Res* 16:285–294, 2013.

31. Hardeland, R. Melatonin and the theories of aging: A critical appraisal of melatonin's role in antiaging mechanisms. *J Pineal Res* 55:325–356, 2013.

32. Morley, J. E. Scientific overview of hormone treatment used for rejuvenation. *Fertil Steril* 99:1807–1813, 2013.

33. Kalyani, R. R., and Egan, J. M. Diabetes and altered glucose metabolism with aging. *Endocrinol Metab Clin North Am* 42:333–347, 2013.

34. Pae, M., Meydani, S. N., and Wu, D. The role of nutrition in enhancing immunity in aging. *Aging Dis* 3:91–129, 2012.

35. U.S. Department of Health and Human Services. *Securing the Benefits of Medical Innovation for Seniors: The Role of Prescription Drugs and Drug Coverage*. Available online at http://aspe.hhs.gov/health/Reports/medicalinnovation. Accessed March 28, 2015.

36. Bernstein, M., and Munoz, N.; Academy of Nutrition and Dietetics. Position of the Academy of Nutrition and Dietetics: Food and nutrition for older adults: Promoting health and wellness. *J Acad Nutr Diet* 112:1255–1277, 2012.

37. Henrotin, Y., and Lambert, C. Chondroitin and glucosamine in the management of osteoarthritis: An update. *Curr Rheumatol Rep* 15:361, 2013.

38. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Protein, and Amino Acids*. Washington, DC: National Academies Press, 2002.

39. Moore, E., Mander, A., Ames, D., et al. Cognitive impairment and vitamin B_{12}: A review. *Int Psychogeriatr* 24:541–556, 2012.

40. Mangialasche, F., Solomon, A., Kåreholt, I., et al. Serum levels of vitamin E forms and risk of cognitive impairment in a Finnish cohort of older adults. *Exp Gerontol* 48:1428–1435, 2013.

41. Farina, N., Isaac, M. G., Clark, A. R., et al. Vitamin E for Alzheimer's dementia and mild cognitive impairment. *Cochrane Database Syst Rev* 11:CD002854, 2012.

42. Li, Y., Liu, S., Man, Y., et al. Effects of vitamins E and C combined with β-carotene on cognitive function in the elderly. *Exp Ther Med* 9:1489–1493, 2015.

43. Tomljenovic, L. Aluminum and Alzheimer's disease: After a century of controversy, is there a plausible link? *J Alzheimer's Dis* 23:567–598, 2011.

44. Gu, Y., and Scarmeas, N. Dietary patterns in Alzheimer's disease and cognitive aging. *Curr Alzheimer Res* 8:510–519, 2011.

45. Maher, R. L., Hanlon, J., and Hajjar, E. R. Clinical consequences of polypharmacy in elderly. *Expert Opin Drug Saf* 13:57–65, 2014.

46. Graham, R. E., Gandhi, T. K, Borus, J., et al. *Risk of Concurrent Use of Prescription Drugs with Herbal and Dietary Supplements in Ambulatory Care.* Available online at http://www.ahrq.gov/downloads/pub/advances2/vol4/Advances-Graham_77.pdf. Accessed March 28, 2015.

47. Moss, M. Drugs as anti-nutrients. *J Nutr Environ Med* 16:149–166, 2007.

48. Bailey, D. G. Fruit juice inhibition of uptake transport: A new type of food–drug interaction. *Br J Clin Pharmacol* 70:645–655, 2010.

49. Administration on Aging, Administration for Community Living, U.S. Department of Health and Human Services. *Profile of Older Americans: 2011*. Available online at http://www.aoa.gov/Aging_Statistics/Profile/2011/16.aspx. Accessed May 24, 2015.

50. Centers for Disease Control and Prevention. *Depression Is Not a Normal Part of Getting Older*. Available online at http://www.cdc.gov/aging/mentalhealth/depression.htm. Accessed March 31, 2015.

51. Penckofer, S., Kouba, J., Byrn, M., and Estwing Ferrans, C. Vitamin D and depression: Where is all the sunshine? *Issues Ment Health Nurs* 31:385–393, 2010.

52. Bauer, J., Biolo, G., Cederholm, T., et al. Evidence-based recommendations for optimal dietary protein intake in older people: A position paper from the PROT-AGE Study Group. *J Am Med Dir Assoc* 14:542–559, 2013.

53. Fulgoni, V. Current protein intake in America: Analysis of the National Health and Nutrition Examination Study 2003–2004. *Am J Clin Nutr* 87:1554–1578, 2008.

54. U.S. Department of Agriculture, Agricultural Research Service. Table 1: Nutrient intakes from food and beverages: Mean amounts consumed per individual, by gender and age in the United States, 2011–2012. *What We Eat in America* (NHANES2011–2012). Available online at http://www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/1112/Table_1_NIN_GEN_11.pdf. Accessed March 29, 2015.

55. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate.* Washington, DC: National Academies Press, 2004.

56. Rampersaud, G. C., Kauwell, G. P., and Bailey, L. B. Folate: A key to optimizing health and reducing disease risk in the elderly. *J Am Coll Nutr* 22:1–8, 2003.

57. Choi, J. H., Yates, Z., Veysey, M., et al. Contemporary issues surrounding folic acid fortification initiatives. *Prev Nutr Food Sci* 19:247–260, 2014.

58. Nicklett, E. J., and Kadell, A. R. Fruit and vegetable intake among older adults: A scoping review. *Maturitas* 75:305–312, 2013.

59. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Calcium and Vitamin D*. Washington, DC: National Academies Press, 2011.

60. Fairweather-Tait, S. J., Wawer, A. A., Gillings, R., et al. Iron status in the elderly. *Mech Ageing Dev* 136–137:22–28, 2014.

61. Cabrera, Á. J. Zinc, aging, and immunosenescence: An overview. *Pathobiol Aging Age Relat Dis* 5:25592, 2015.

62. Jahangir, E., De Schutter, A., and Lavie, C. J. Low weight and overweightness in older adults: Risk and clinical management. *Prog Cardiovasc Dis* 57:127–133, 2014.

63. Gershwin, M. E., Borchers, A. T., Keen, C. L., et al. Public safety and dietary supplementation. *Ann NY Acad Sci* 1190:104–117, 2010.

64. Ribnicky, D. M., Poulev, A., Schmidt, B., et al. Evaluation of botanicals for improving human health. *Am J Clin Nutr* 87:472S–475S, 2008.

65. Newmaster, S. G., Grguric, M., Shanmughanandhan, D., et al. DNA barcoding detects contamination and substitution in North American herbal products. *BMC Medicine* 11:222, 2013.

66. U.S. Food and Drug Administration. *Safety Alerts and Advisories.* Available online at http://www.fda.gov/Food/RecallsOutbreaksEmergencies/SafetyAlertsAdvisories. Accessed April 6, 2015.

67. Saper, R. B., Phillips, R. S., Sehgal, A., et al. Lead, mercury, and arsenic in US- and Indian-manufactured Ayurvedic medicines sold via the Internet. *JAMA* 300:915–923, 2008.

68. Kennedy, D. A., and Seely, D. Clinically based evidence of drug–herb interactions: A systematic review. *Expert Opin Drug Saf* 9:79–124, 2010.

69. Bjelakovic, G., Nikolova, D., and Gluud, C. Antioxidant supplements and mortality. *Curr Opin Clin Nutr Metab Care* 17:40–44, 2014.

70. Garber, C. E., Blissmer, B., Deschenes, M. R., et al.; American College of Sports Medicine. American College of Sports Medicine position stand: Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Med Sci Sports Exerc* 43:1334–1359, 2011.

71. U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans*. Available online at http://www.health.gov/paguidelines. Accessed March 24, 2015.

72. Nutrition.gov. *Elderly Nutrition Program* Available online at http://www.nutrition.gov/food-assistance-programs/elderly-nutrition-program. Accessed March 30, 2015.

Chapter 17

1. Centers for Disease Control and Prevention. *CDC Estimates of Food-Borne Illness in the United States: 2011*. Available online at http://www.cdc.gov/foodborneburden/2011-foodborne-estimates.html. Accessed April 10, 2015.

2. U.S. Food and Drug Administration. *Food Code*. Available online at http://www.fda.gov/food/guidanceregulation/retailfoodprotection/foodcode. Accessed April 10, 2015.

3. U.S. Food and Drug Administration, Department of Agriculture, and Environmental Protection Agency. *Food Safety from Farm to Table: A New Strategy for the 21st Century*, February 21, 1997. Available online at http://www.cdc.gov/ncidod/foodsafe/report.htm. Accessed April 10, 2015.

4. U.S. Food and Drug Administration. *FDA Food Safety Modernization Act (FSMA)*. Available online at http://www.fda.gov/Food/GuidanceRegulation/FSMA/default.htm. Accessed April 10, 2015.

5. Centers for Disease Control and Prevention. *Foodborne Diseases Active Surveillance Network (FoodNet)*. Available online at http://www.cdc.gov/foodnet. Accessed April 10, 2015.

6. U.S. Food and Drug Administration, Center for Food Safety and Nutrition. *Bad Bug Book (Second Edition). Foodborne Pathogenic Microorganisms and Natural Toxins Handbook.* Available online at http://www.fda.gov/food/foodborneillnesscontaminants/causesofillnessbadbugbook/default.htm. Accessed May 27, 2015.

7. Scallan, E., Hoekstra, R. M., Angulo, F. J., et al. Foodborne illness acquired in the United States—Major pathogens. *Emerg Infect Dis* 17:7–15, 2011.

8. Centers for Disease Control and Prevention. *Salmonella Is a Sneaky Germ: Seven Tips for Safer Eating*. Available online at http://www.cdc.gov/features/vitalsigns/foodsafety. Accessed May 27, 2015.

9. Centers for Disease Control and Prevention. *Multistate Outbreak of Shiga Toxin-Producing* Escherichia coli *O157:H7 Infections Linked to Organic Spinach and Spring Mix Blend (Final Update)*. Available online at http://www.cdc.gov/ecoli/2012/O157H7-11-12. Accessed May 29, 2015.

10. Centers for Disease Control and Prevention. *Multistate Outbreak of Shiga Toxin-Producing* Escherichia coli *O157:H7 Infections Linked to Ready-to-Eat Salads (Final Update)*. Available online at http://www.cdc.gov/ecoli/2013/O157H7-11-13/index.html. Accessed May 27, 2015.

11. Centers for Disease Control and Prevention. *Investigation Announcement: Multistate Outbreak of* E. coli *O157:H7 Infections Associated with Lebanon Bologna.* Available online at http://www.cdc.gov/ecoli/2011/O157_0311/index.html. Accessed May 29, 2015.

12. Centers for Disease Control and Prevention. Outbreak of *Escherichia coli* O104:H4 infections associated with sprout consumption—Europe and North America, May–July 2011. *MMWR Morb Mortal Wkly Rep* 62:1029–1031, 2013.

13. Williams, A., and Oyarzabal, O. A. Prevalence of *Campylobacter* spp. in skinless, boneless retail broiler meat from 2005 through 2011 in Alabama, USA. *BMC Microbiol* 12:184, 2012.

14. Centers for Disease Control and Prevention. Vital signs: *Listeria* illnesses, deaths, and outbreaks—United States, 2009–2011. *Morb Mortal Wkly Rep* 62:448–452, 2013.

15. Lamont, R. F., Sobel, J., Mazaki-Tovi, S., et al. *Listeriosis* in human pregnancy: A systematic review. *J Perinat Med* 39:227–236, 2011.

16. Koepke, R., Sobel, J., and Arnon, S. S. Global occurrence of infant botulism, 1976–2006. *Pediatrics* 122:73–82, 2008.

17. Barnes, M., Britton, P. N., and Singh-Grewal, D. Of war and sausages: A case-directed review of infant botulism. *J Paediatr Child Health* 49:E232–E234, 2013.

18. Centers for Disease Control and Prevention. *Norovirus Overview*. Available online at http://www.cdc.gov/norovirus/about/overview.html. Accessed April 12, 2015.

19. Hall, A. J., Eisenbart, V. G., Etingüe, A. L., et al. Epidemiology of foodborne norovirus outbreaks, United States, 2001–2008. *Emerg Infect Dis* 18:1566–1573, 2012.

20. Liu, Y., and Wu, F. Global burden of aflatoxin-induced hepatocellular carcinoma: A risk assessment. *Environ Health Perspect* 118:818–824, 2010.

21. Centers for Disease Control and Prevention. *Cryptosporidium*. Available online at http://www.cdc.gov/parasites/crypto/epi.html. Accessed April 12, 2015.

22. Centers for Disease Control and Prevention. *vCJD (Variant Creutzfeldt-Jakob Disease)*. Available online at http://www.cdc.gov/ncidod/dvrd/vcjd/factsheet_nvcjd.htm. Accessed April 12, 2015.

23. Centers for Disease Control and Prevention. *BSE (Bovine Spongiform Encephalopathy, or Mad Cow Disease)*. Available online at http://www.cdc.gov/ncidod/dvrd/bse. Accessed April 12, 2015.

24. FoodSaftey.gov. *Charts: Food Safety at a Glance, Storage Times for the Refrigerator and Freezer*. Available online at http://www.foodsafety.gov/keep/charts/storagetimes.html. Accessed April 13, 2015.

25. FoodSaftey.gov. *Charts: Food Safety at a Glance, Egg Storage Chart*. Available online at http://www.foodsafety.gov/keep/charts/eggstorage.html. Accessed April 13, 2015.

26. FoodSaftey.gov. *Charts: Food Safety at a Glance, Safe Minimum Cooking Temperatures*. Available online at http://www.foodsafety.gov/keep/charts/mintemp.html. Accessed April 12, 2015.

27. U.S. Department of Agriculture, Food Safety and Inspection Service. *Danger Zone (40°–140°)*. Available online at http://www.fsis.usda.gov/wps/wcm/connect/8b705ede-f4dc-4b31-a745-836e66eeb0f4/Danger_Zone.pdf?MOD=AJPERES. Accessed May 27, 2015.

28. U.S. Environmental Protection Agency. *Setting Tolerances for Pesticide Residues in Foods* (Pesticides: Topical & Chemical Fact Sheets). Available online at http://www.epa.gov/opp00001/factsheets/stprf.htm. Accessed April 16, 2015.

29. U.S. Environmental Protection Agency. *Assessing Health Risks from Pesticides* (Pesticides: Topical & Chemical Fact Sheets). Available online at http://www.epa.gov/pesticides/factsheets/riskassess.htm. Accessed April 16, 2015.

30. U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition. *Pesticide Monitoring Program Fiscal Year 2012 Pesticide Report*. Available online at http://www.fda.gov/downloads/Food/FoodborneIllnessContaminants/Pesticides/UCM432758.pdf. Accessed April 16, 2015.

31. U.S. Department of Agriculture. *Pesticide Data Program: Annual Summary, Calendar Year 2013*. Available online at http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5110007. Accessed April 16, 2015.

32. U.S. Department of Agriculture, Agricultural Marketing Service. *National Organic Program*. Available online at http://www.ams.usda.gov/AMSv1.0/nop. Accessed April 16, 2015.

33. U.S. Department of Agriculture, Economic Research Service. *Organic Market Overview.* Available online at http://www.ers.usda.gov/topics/natural-resources-environment/organic-agriculture/organic-market-overview.aspx. Accessed April 17, 2015.

34. Crinnion, W. J. Organic foods contain higher levels of certain nutrients, lower levels of pesticides, and may provide health benefits for the consumer. *Altern Med Rev* 1:4–12, 2010.

35. Mukherjee, A., Speh, D., Dyck, E., et al. Preharvest evaluation of coliforms, *E. coli*, *Salmonella* and *E. coli* O157:H7 in organic and conventional produce grown by Minnesota farmers. *J Food Prot* 67: 894–900, 2004.

36. Dangour, A. D., Lock, K., Hayter, A., et al. Nutrition-related health effects of organic foods: A systematic review. *Am J Clin Nutr* 92:203–210, 2010.

37. Dangour, A. D., Dodhia, S. K., Hayter, A., et al. Nutritional quality of organic foods: A systematic review. *Am J Clin Nutr* 90:680–685, 2009.

38. Seufert, V., Ramankutty, N., and Foley, J. A. Comparing the yields of organic and conventional agriculture. *Nature* 485:229–232, 2012.

39. Animal Health Institute. *FDA Approval: About the FDA's Safety Assessment for Food Animals.* Available online at http://www.ahi.org/issues-advocacy/animal-antibiotics/fda-approval/#A. Accessed April 17, 2015.

40. U.S. Food and Drug Administration. *FDA Takes Significant Steps to Address Antimicrobial Resistance*, December 11, 2013. Available online at http://www.fda.gov/AnimalVeterinary/NewsEvents/CVMUpdates/ucm378166.htm. Accessed April 17, 2015.

41. U.S. Food and Drug Administration. *Report on the U.S. Food and Drug Administration's Review of the Safety of Recombinant Bovine Somatotropin*, April 23, 2009. Available online at http://www.fda.gov/animalveterinary/safetyhealth/productsafetyinformation/ucm130321.htm. Accessed April 17, 2015.

42. U.S. Food and Drug Administration. *Fish: What Pregnant Women and Parents Should Know* (Draft Updated Advice by FDA and EPA), June 2014. Available online at http://www.fda.gov/Food/FoodborneIllnessContaminants/Metals/ucm393070.htm. Accessed April 17, 2015.

43. U.S. Public Health Service. *United States Proposed Standard Milk Ordinance, Public Health Reports*. Washington, DC: U.S. Public Health Service, November 7, 1924.

44. U.S. Food and Drug Administration. *2013 Revision of the Grade "A" Pasteurized Milk Ordinance*. Available online at http://www.fda.gov/food/guidanceregulation/guidancedocumentsregulatoryinformation/milk/ucm389905.htm. Accessed April 17, 2015.

45. Riboldi, B. P., Vinhas, A. M., and Moreira, J. D. Risks of dietary acrylamide exposure: A systematic review. *Food Chem* 157C:310–322, 2014.

46. Pedreschi, F., Mariotti, M. S., and Granby, K. Current issues in dietary acrylamide: Formation, mitigation and risk assessment. *J Sci Food Agric* 94:9–20, 2014.

47. U.S. Food and Drug Administration. *Food Facts: Food Irradiation: What You Need to Know,* November 2014. Available online at http://www.fda.gov/downloads/Food/IngredientsPackagingLabeling/UCM262295.pdf. Accessed April 17, 2015.

48. National Institutes of Health, National Institute of Environmental Health Sciences. *Bisphenol A (BPA).* Available online at http://www.niehs.nih.gov/health/topics/agents/sya-bpa. Accessed April 18, 2015.

49. U.S. Food and Drug Administration, *Bisphenol A (BPA): Use in Food Contact Application*. Available online at http://www.fda.gov/Food/IngredientsPackagingLabeling/FoodAdditivesIngredients/ucm064437.htm. Accessed April 18, 2015.

50. U.S. Food and Drug Administration, *Everything Added to Food in the United States (EAFUS)*, November 2011. Available online at http://www.fda.gov/Food/IngredientsPackagingLabeling/FoodAdditivesIngredients/ucm115326.htm. Accessed April 17, 2015.

51. U.S. Food and Drug Administration, International Food Information Center. *Overview of Food Ingredients, Additive, and Colors*, November 2004; revised April 2010. Available online at http://www.fda.gov/Food/IngredientsPackagingLabeling/FoodAdditivesIngredients/ucm094211.htm. Accessed April 17, 2015.

52. Vally, H., and Misso, N. L. Adverse reactions to the sulphite additives. *Gastroenterol Hepatol Bed Bench* 5:16–23, 2012.

53. Rajan, J. P., Simon, R. A., and Bosso, J. V. Prevalence of sensitivity to food and drug additives in patients with chronic idiopathic urticaria. *J Allergy Clin Immunol Pract* 2:168–171, 2014.

54. U.S. Food and Drug Administration, *Color Additives: In Food*. Available online at http://www.fda.gov/ForIndustry/ColorAdditives/ColorAdditivesinSpecificProducts/InFood/default.htm. Accessed April 18, 2015.

55. Sindelar, J. J., and Milkowski, A. L. Human safety controversies surrounding nitrate and nitrite in the diet. *Nitric Oxide* 26:259–266, 2012.

FOCUS ON Biotechnology

1. Cohen, S. N., Chang, A. C., Boyer, H. W., and Helling, R. B. Construction of biologically functional bacterial plasmids *in vitro. Proc Natl Acad Sci USA* 70:3240–3244, 1973.

2. Zimmer, C. Genes are us. And them. *National Geographic.* Available online at http://ngm.nationalgeographic.com/2013/07/125-explore/shared-genes. Accessed April 19, 2015.

3. Wheeler, M. B. Transgenic animals in agriculture. *Nature Education Knowledge* 4:1, 2013. Available online at http://www.nature.com/scitable/knowledge/library/transgenic-animals-in-agriculture-105646080. Accessed April 19, 2015.

4. Brookes, G., and Barfoot, P. Environmental impacts of genetically modified (GM) crop use 1996–2013: Impacts on pesticide use and carbon emissions. *GM Crops Food*. 6:103–133, 2015.

5. Gonsalves, D., and Ferreira, S. *Transgenic Papaya: A Case for Managing Risks of Papaya Ringspot Virus in Hawaii*. Available online at http://www.plantmanagementnetwork.org/pub/php/review/2003/papaya. Accessed April 21, 2015.

6. World Health Organization. *Biofortification of Staple Crops*. Available online at http://www.who.int/elena/titles/biofortification/en. Accessed April 20, 2015.

7. Aung, M. S., Masuda, H., Kobayashi, T., et al. Iron biofortification of Myanmar rice. *Front Plant Sci* 4:158, 2013.

8. Ye, X., Al-Babili, S., Kloti, A., et al. Engineering the provitamin A (beta-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. *Science* 287:303–305, 2000.

9. Tang, G., Hu, Y., Yin, S. A., et al. β-Carotene in Golden Rice is as good as β-carotene in oil at providing vitamin A to children. *Am J Clin Nutr* 96:658–664, 2012.

10. Moghissi, A. A., Pei, S., and Liu, Y. Golden Rice: Scientific, regulatory and public information processes of a genetically modified organism. *Crit Rev Biotechnol* 15:1-7, 2015.

11. International Rice Research Institute (IRRI). *What Is the Status of the Golden Rice Project Coordinated by IRRI?* Available online at http://irri.org/golden-rice/faqs/what-is-the-status-of-the-golden-rice-project-coordinated-by-irri. Accessed April 20, 2015.

12. Donald Danforth Plant Science Center. *BioCassava Plus.* Available online at https://www.danforthcenter.org/scientists-research/research-institutes/institute-for-international-crop-improvement/crop-improvement-projects/biocassava-plus. Accessed April 20, 2015.

13. Lim, X. Cheese: The GMO food even die-hard GMO opponents eat and love (and oppose a label for). *Genetic Literacy Project*, April 29, 2014. Available online at http://www.geneticliteracyproject.org/2014/04/29/cheese-the-gmo-food-that-even-die-hard-gmo-opponents-eat-and-love. Accessed April 21, 2015.

14. Food and Agriculture Organization of the United Nations, Fisheries and Aquaculture Department. *Biotechnology*. Available online at http://www.fao.org/fishery/topic/12316/en. Accessed April 21, 2015.

15. Clifford, H. AquAdvantage salmon—A pioneering application of biotechnology in aquaculture. *BMC Proc* 8(suppl 4):O31, 2014.

16. GMO Compass. *USA: New GM Soybean with Higher Oleic Acid Content Approved*. Available online at http://www.gmo-compass.org/eng/news/519.usa_new_gm_soybean_higher_oleic_acid_content_approved.html. Accessed April 20, 2015.

17. Chen, H., and Lin, Y. Promise and issues of genetically modified crops. *Curr Opin Plant Biol* 16:255–260, 2013.

18. Hunter, S. C., and Cahoon, E. B. Enhancing vitamin E in oilseeds: Unraveling tocopherol and tocotrienol biosynthesis. *Lipids* 42:97–108, 2007.

19. Pollack, A. U.S.D.A. approves modified potato. Next up: French fry fans. *New York Times Business Day*, November 7, 2014. Available online at http://www.nytimes.com/2014/11/08/business/genetically-modified-potato-from-simplot-approved-by-usda.html?_r=0. Accessed April 20, 2015.

20. Clive, J. *Global Status of Commercialized Biotech/GM Crops: 2014* (ISAAA Brief no. 49). Ithaca, NY: ISAAA, 2014.

21. Goodman, R. E., Panda, R., and Ariyarathna, H. Evaluation of endogenous allergens for the safety evaluation of genetically engineered food crops: Review of potential risks, test methods, examples and relevance. *J Agric Food Chem* 61:8317–8332, 2013.

22. Nordlee, J. A., Taylor, S. L., Townsend, J. A., et al. Identification of a Brazil-nut allergen in transgenic soybeans. *N Engl J Med* 334:688–692, 1996.

23. Goldstein, D. A. Tempest in a tea pot: How did the public conversation on genetically modified crops drift so far from the facts? *J Med Toxicol* 10:194–201, 2014.

24. Yau, Y. Y., and Stewart, Jr., C. N. Less is more: Strategies to remove marker genes from transgenic plants. *BMC Biotechnol* 13:36, 2013.

25. Carpenter, J. E. Impact of GM crops on biodiversity. *GM Crops* 2:7–23, 2011.

26. Monsanto. *Pink Bollworm Resistance to GM Cotton in India*. Available online at http://www.monsanto.com/newsviews/pages/india-pink-bollworm.aspx. Accessed April 22, 2015.

27. Committee on the Impact of Biotechnology on Farm-Level Economics and Sustainability, National Research Council. *Impact of Genetically Engineered Crops on Farm Sustainability in the United States*. Washington, DC: National Academies Press, 2010. Available online at http://www.nap.edu/catalog.php?record_id=12804. Accessed April 22, 2015.

28. Bawa, A. S., and Anilakumar, K. R. Genetically modified foods: Safety, risks and public concerns—A review. *J Food Sci Technol* 50:1035–1046, 2013.

29. Lu, Y., Wu, K., Jiang, Y., et al. Mirid bug outbreaks in multiple crops correlated with wide-scale adoption of Bt cotton in China. *Science* 328:1151–1154, 2010.

30. U.S. Food and Drug Administration. *Biotechnology: Genetically Engineered Plants for Food and Feed*. Available online at http://www.fda.gov/food/foodscienceresearch/biotechnology/default.htm. Accessed April 22, 2015.

Chapter 18

1. Food and Agriculture Organization of the United Nations. *The State of Food Insecurity in the World 2014*. Available online at http://www.fao.org/3/a-i4030e.pdf. Accessed April 11, 2015.

2. World Health Organization. *Children: Reducing Mortality*. Available online at http://www.who.int/mediacentre/factsheets/fs178/en. Accessed April 28, 2015.

3. Central Intelligence Agency. *The World Factbook*. Available online at https://www.cia.gov/library/publications/the-world-factbook. Accessed April 10, 2015.

4. United Nations Children's Fund. *Levels and Trends in Child Malnutrition*. Available online at http://data.unicef.org/corecode/uploads/document6/uploaded_pdfs/corecode/LevelsandTrendsMalNutrition_Summary_2014_132.pdf. Accessed April 10, 2015.

5. Martins, V. J., Toledo Florêncio, T. M., Grillo, L. P., et al. Long-lasting effects of undernutrition. *Int J Environ Res Public Health* 8: 1817–1846, 2011.

6. World Health Organization. Global Health Observatory (GHO) data. *Causes of Child Mortality, 2013*. Available online at http://www.who.int/gho/child_health/mortality/causes/en. Accessed April 14, 2015.

7. World Health Organization. *Obesity and Overweight*. Available online at http://www.who.int/mediacentre/factsheets/fs311/en. Accessed April 12, 2015.

8. World Health Organization. *Global Status Report of Noncommunicable Disease 2014*. Available online at http://www.who.int/nmh/publications/ncd-status-report-2014/en. Accessed April 14, 2015.

9. Kelly, T., Yang, W., Chen, C.-S., et al. Global burden of obesity in 2005 and projections to 2030. *Int J Obes (Lond)* 32:1431–1437, 2008.

10. World Health Organization. *The Double Burden of Disease*. Available online at http://www.who.int/nutrition/topics/2_background/en/index1.html. Accessed April 13, 2015.

11. World Bank. *Poverty and Equity Data*. Available online at http://www.worldbank.org/en/topic/measuringpoverty/overview#1. Accessed April 13, 2015.

12. World Bank. *The State of Social Safety Nets 2014*. Available online at http://www.worldbank.org/en/topic/safetynets/publication/the-state-of-social-safety-nets-2014. Accessed April 28, 2015.

13. World Bank. *Poverty and Equity Data: Global Poverty Indicators*. Available online at http://povertydata.worldbank.org/poverty/home. Accessed April 19, 2015.

14. Population Reference Bureau. *World Population Data Sheet*. Available online at http://www.prb.org/pdf14/2014-world-population-data-sheet_eng.pdf. Accessed April 18, 2015.

15. Food and Agriculture Organization of the United Nations. Feeding the world. *FAO Statistical Yearbook 2012*. Available online at http://www.fao.org/docrep/015/i2490e/i2490e03a.pdf. Accessed April 25, 2015.

16. Canning, P., Charles, A., Huang, S., et al. *Energy Use in the U.S. Food System*. Available online at http://www.ers.usda.gov/media/136418/err94_1_.pdf. Accessed April 20, 2015.

17. Gardner, B. *Global Food Futures: Feeding the World in 2050*. London: Bloomsbury Press, 2013.

18. Steinfeld, H., Gerber, P., Wassenaar, T., et al.; Food and Agricultural Organization of the United Nations. *Livestock's Long Shadow: Environmental Issues and Options*, 2006. Available online at http://www.fao.org/docrep/010/a0701e/a0701e00.HTM. Accessed April 20, 2015.

19. Economides, M. Corn-based ethanol: The real cost. *Energy Tribune,* May 13, 2011. Available online at http://fuelfix.com/blog/2011/05/13/corn-based-ethanol-the-real-cost. Accessed April 18, 2015.

20. World Watch Institute. *Increase in Grain Prices Affects U.S. Food Donations*. Available online at http://www.worldwatch.org/node/5408. Accessed April 18, 2015.

21. Food and Agriculture Organization of the United Nations. *General Situation of World Fish Stocks*. Available online at http://www.fao.org/newsroom/common/ecg/1000505/en/stocks.pdf. Accessed April 18, 2015.

22. National Oceanic and Atmospheric Administration. *Aquaculture and the Environment*. Available online at http://www.nmfs.noaa.gov/aquaculture/faqs/faq_aq_environment.html. Accessed April 19, 2015.

23. Sabaté, J., Sranacharoenpong, K., Harwatt, H., et al. The environmental cost of protein food choices. *Public Health Nutr* (suppl 1):s1–s7, 2014.

24. Audsley, E., Brander, M., Chatterton, J., et al. *How Low Can We Go? An Assessment of Greenhouse Gas Emissions from the UK Food System and the Scope for Reduction by 2050.* Available online at http://assets.wwf.org.uk/downloads/how_low_summary_1.pdf. Accessed April 19, 2015.

25. Trehan, I., Goldbach, H. S., LaGrone, L. N., et al. Antibiotics as part of the management of severe acute malnutrition. *N Engl J Med* 368:425–435, 2013.

26. World Health Organization. *Micronutrient Deficiencies. Iron Deficiency Anaemia*. Available online at http://www.who.int/nutrition/topics/ida/en/index.html. Accessed April 19, 2015.

27. Centers for Disease Control and Prevention. *Parasites: Hookworm*. Available online http://www.cdc.gov/parasites/hookworm. Accessed April 19, 2015.

28. Semba, R. D. Vitamin A as "anti-infective" therapy, 1920–1940. *J Nutr* 129:783–791, 1999.

29. Brundtland, G. H. Nutrition and infection: Malnutrition and mortality in public health. *Nutr Rev* 58(II):S1–S4, 2000.

30. Mellanby, E. Diet and disease, with special reference to the teeth, lungs, and prenatal feeding. *Lancet* 1:151–519, 1926.

31. Green, H. N., and Mellanby, E. Vitamin A as an anti-infective agent. *Br Med J* 2:691–696, 1928.

32. Scrimshaw, N. S., Taylor, C. E., and Gordon, J. E. Interaction of nutrition and infection. *Am J Med Sci* 237:367–403, 1959.

33. West, C. E. Vitamin A and measles. *Nutr Rev* 58(II):S46–S54, 2000.

34. Markowitz, L.E., Nzilambi, N., Driskell, W. J., et al. Vitamin A levels and mortality among hospitalized measles patients, Kinshasa, Zaire. *J Trop Pediatr* 35:109–112, 1989.

35. Centers for Disease Control and Prevention. *Measles and Rubella*. Available online at http://www.cdc.gov/globalhealth/measles. Accessed April 19, 2015.

36. World Health Organization. *Vitamin A Supplementation in Infants and Children 6–59 Months of Age*. Available online at http://www.who.int/nutrition/publications/micronutrients/guidelines/vas_6to59_months/en. Accessed April 19, 2015.

37. World Health Organization. *Effect and Safety of Salt Iodization to Prevent Iodine Deficiency Disorders: A Systematic Review with Meta-Analyses*. Available online at http://www.who.int/nutrition/publications/micronutrients/effect_safety_saltiodization/en. Accessed April 19, 2015.

38. World Health Organization. *Is It True That Lack of Iodine Really Causes Brain Damage?* Available online at http://www.who.int/features/qa/17/en. Accessed April 19, 2015.

39. World Health Organization. *Micronutrient Deficiencies: Vitamin A Deficiency: The Challenge.* Available online at http://www.who.int/nutrition/topics/vad/en/index.html. Accessed April 19, 2015.

40. World Health Organization. *Intermittent Iron and Folic Acid Supplementation in Menstruating Women.* Available online at http://www.who.int/nutrition/publications/micronutrients/guidelines/summary_guideline_fe_folicacid_women.pdf. Accessed April 19, 2015.

41. Food and Agriculture Organization of the United Nations. *Preventing Micronutrient Malnutrition: A Guide to Food-Based Approaches*. Available online at http://www.fao.org/docrep/x5244e/x5244e03.htm. Accessed April 19, 2015.

42. Wessells, K. R., and Brown, K. H. Estimating the global prevalence of zinc deficiency: Results based on zinc availability in national food supplies and the prevalence of stunting. *PLoS One* 7:e50568, 2012.

43. Loscalzo, J. Keshan disease, selenium deficiency, and the selenoproteome. *N Engl J Med* 370:1756–1760, 2014.

44. International Osteoporosis Foundation. *Facts and Statistics*. Available online at http://www.iofbonehealth.org/facts-statistics. Accessed February 27, 2015.

45. United Nations. *Sustainable Development Goals*. Available online at http://www.un.org/sustainabledevelopment/sustainable-development-goals/#. Accessed October 1, 2015.

46. United Nations. *We Can End Poverty: Millennium Development Goals and Beyond 2015*. Available online at http://www.un.org/millenniumgoals/poverty.shtml. Accessed April 27, 2015.

47. Population Reference Bureau. *Family Planning Worldwide 2013 Data Sheet*. Available online at http://www.prb.org/pdf13/family-planning-2013-datasheet_eng.pdf. Accessed April 25, 2015.

48. Reading, B. F.; Earth Policy Institute. *Education Leads to Lower Fertility and Increased Prosperity. Data Highlights*, May 12, 2011. Available online at http://www.earth-policy.org/data_highlights/2011/highlights13. Accessed April 24, 2015.

49. Seufert, V., Ramankutty, N., and Foley, J. A. Comparing the yields of organic and conventional agriculture. *Nature* 485: 229–232, 2012.

50. United Nations Children's Fund. *Adequately Iodized Salt Can Protect Children from Brain Damage, But Only Three Quarters of the World's Households Are Using It.* Available online at http://data.unicef.org/nutrition/iodine. Accessed April 19, 2015.

51. United Nations Children's Fund. *Sustainable Elimination of Iodine Deficiency*. Available online at http://www.childinfo.org/files/idd_sustainable_elimination.pdf. Accessed April 19, 2015.

52. United Nations Children's Fund. *Vitamin A: A Global Initiative*. Available online at http://www.unicef.org/immunization/files/Vit_A_strategy.pdf. Accessed April 22, 2015.

53. Ogden, C. L., Carroll, M. D., Kit, B. K., and Flegal, K. M. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA* 311:806–814, 2014.

54. Coleman-Jensen, A., Gregory, C., and Singh, A. *Household Food Security in the United States in 2013,* ERR-173, U.S. Department of Agriculture, Economic Research Service. September 2014. Available online at http://www.ers.usda.gov/media/1565415/err173.pdf. Accessed August 20, 2015.

55. U.S. Census Bureau. *Poverty: 2013 Highlights*. Available online at http://www.census.gov/hhes/www/poverty/about/overview. Accessed April 22, 2015.

56. Office of Minority Health, U.S. Department of Health and Human Services. *American Indian/Alaska Native Profile.* Available online at http://minorityhealth.hhs.gov/omh/browse.aspx?lvl=3&lvlid=62. Accessed June 8, 2015.

57. Centers for Disease Control and Prevention. *A Look Inside Food Deserts.* Available online at http://www.cdc.gov/Features/FoodDeserts. Accessed April 22, 2015.

58. Agriculture Marketing Service, U.S. Department of Agriculture. *Food Deserts.* Available online at http://apps.ams.usda.gov/fooddeserts/fooddeserts.aspx. Accessed April 25, 2015.

59. U.S. Census Bureau. Table 692: Money income of households—Distribution by income level and selected characteristics: 2009. *The 2012 Statistical Abstract.* Available online at http://www.census.gov/compendia/statab/2012/tables/12s0692.pdf. Accessed April 23, 2015.

60. Centers for Disease Control and Prevention. QuickStats: Infant Mortality Rates, by Race and Hispanic Ethnicity of Mother. *MMWR Morb Mortal Wkly Rep* Jan 10, 2014. Available online at http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6301a9.htm. Accessed April 22, 2015.

61. National Alliance to End Homelessness. *State of Homelessness in America 2014.* Available online at http://www.endhomelessness.org/library/entry/the-state-of-homelessness-2014. Accessed April 22, 2015.

62. National Women's Law Center. *Insecure &Unequal Poverty and Income among Women and Families 2000–2012.* Available online at http://www.nwlc.org/sites/default/files/pdfs/final_2013_nwlc_povertyreport.pdf. Accessed April 22, 2015.

63. Federal Interagency Forum on Aging. *Older Americans 2012: Key Indicators of Well-Being.* Available online at http://www.agingstats.gov/agingstatsdotnet/Main_Site/Data/2012_Documents/Docs/EntireChartbook.pdf. Accessed April 22, 2015.

64. Oliveira, V.; Economic Research Service, U.S. Department of Agriculture. *The Food Assistance Landscape: FY 2014 Annual Report* (Economic Information Bulletin no. 137), March 2015. Available online at http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib137.aspx. Accessed April 22, 2015.

65. Oliveira, V.; Economic Research Service, U.S. Department of Agriculture. *The Food Assistance Landscape: FY 2013 Annual Report* (Economic Information Bulletin no. 120), February 2014. Available online at http://www.ers.usda.gov/media/1282272/eib120.pdf. Accessed April 22, 2015.

66. Feeding America. *How We Work.* Available online at http://www.feedingamerica.org/our-response/how-we-work. Accessed April 22, 2015.

67. Gunders, D.; National Resource Defense Council. *Wasted: How America Is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill.* Available online at http://www.nrdc.org/food/files/wasted-food-ip.pdf. Accessed April 22, 2015.

68. Economic Research Service, USDA Center for Nutrition Policy and Promotion, U.S. Department of Agriculture. *USDA's Healthy Eating Index and Nutrition Information.* Available online at http://www.cnpp.usda.gov/HealthyEatingIndex.htm. Accessed April 22, 2015.

Index

Note: Entries followed by an "f" may be found in a figure; entries followed by a "t" may be found in a table.

A

Abnormal growth, infants, 568
Absorption, 84–86, 86f, *See also* Digestive tract
  alcohol and, 192–193
  amino acids and, 208–209, 209f
  carbohydrates and, 119,119f
  calcium and, 428, 428f
  copper and, 459, 459f
  definition of, 75
  iron and, 337
  minerals and, 416–417, 417f
  water and, 390
  zinc and, 455, 456f
Acceptable Daily Intake (ADI), 146t, 147
Acceptable macronutrient distribution ranges (AMDRs), 37f, 39
Accessory organs, digestive system and, 76, 76f
Accidental food contaminants, 661
Accutane, 357
Acesulfame K, 146t
Acetaldehyde, 194, 194f
Acetylcholine, thiamin deficiency and, 312
Acetyl-CoA, 103–104
  aerobic metabolism and, 505
  alcohol breakdown and, 194, 194f
  fat synthesis and, 257
  formation, 125
  ketones and, 169
  nutrient conversion and, 253
Acid-base balance
  proteins and, 218
  water and, 387
Acrodermatitis enteropathica, 457–458
Acrylamide, 661
Active lifestyles, creating, 500–501
Active transport, 85, 86f
Adaptive thermogenesis, 267
Added sugars, 111, 112–114, 114f
Additives. *See* Food additives
Adenosine triphosphate (ATP)
  acetyl-CoA and, 103–104
  aerobic capacity and, 507–508
  cellular respiration and, 103, 104, 104f
  citric acid cycle and, 104
  electron transport chain and, 104
  energy metabolism and, 502–506
  food energy conversion and, 252–253, 254f
  magnesium and, 437, 437f
  oxidation-reduction reactions and, 104
  phosphorus and, 435, 435f
  production, 103–104, 103f
  source changes over time, 503, 503f
Adequate intakes (AIs), 38–39
Adipocytes, 243
Adipokines, 243
Adipose tissue, 165, 165f
Adjustable gastric banding, 280, 280f
Adolescents, 596–604
  alcohol use and, 604
  anabolic steroids and, 526, 526f
  athletics and, 602–603, 603f
  calcium and, 598
  eating disorders and, 602
  energy-yielding nutrients and, 598, 598f
  growth and, 597, 597f
  growth spurts and, 597
  iron and, 599–600
  meeting nutritional needs of, 600–601
  menarche and, 597
  micronutrients and, 598–600
  MyPlate recommendations and, 600f, 601f
  nutrient needs and, 597–600
  oral contraceptive use and, 603
  puberty and, 597
  sexual maturation and, 597
  soda ban and, 599
  special concerns and, 601–604
  teenage pregnancy, 554, 554f, 603–604
  tobacco use and, 604
  vegetarian diets and, 601–602, 602f
  vitamins and, 598
  weight loss and, 603
  zinc and, 600
Adrenaline, gluconeogenesis and, 125
Aerobic capacity (VO_2max)
  requirements and, 493, 493f
  training and, 507–508, 508f
Aerobic exercise. *See also* Exercise
  cardiopulmonary endurance and, 492–493, 493f
  exercise intensity and, 506–507, 507f
  recommendations and, 498–499, 499f
Aerobic metabolism, 125, 502, 504f, 505, 505f
Aflatoxin, 648–649
Aging. *See also* Older adults
  age-related bone loss, 421–422, 421f
  aging population, 610, 610f
  Alzheimer's disease and, 617–618
  atrophic gastritis and, 615
  basal metabolism and, 255
  body composition and, 246f, 247, 614–615
  caloric restriction and, 608–609
  cancer and, 616, 616f
  cataracts and, 613, 613f
  causes of, 611–621
  cognition and, 617–618
  compression of morbidity and, 610, 610f
  definition of, 608
  dementia and, 617–618
  DHEA levels and, 616
  digestive system changes and, 99
  estimated energy requirements and, 262
  estrogen levels and, 615
  gastrointestinal function and, 614
  genetics, environment, lifestyle and, 611–612, 612f
  growth hormone and, 616
  heart and blood vessels and, 614
  hormone levels and, 615–616
  immune function and, 616
  insulin levels and, 616
  kidneys and, 614
  life expectancy and, 609–610
  life span and, 608–609
  liver function and, 614
  longevity and, 612
  macular degeneration and, 613
  malnutrition and, 612–621, 612t
  melatonin levels and, 616
  menopause and, 615–616
  mobility and, 617
  osteoarthritis and, 617, 617f
  oxidative damage and, 626–628, 628f
  pancreas function and, 614
  periodontal disease and, 615
  physical frailty and, 614–615
  programmed cell death and, 611
  reserve capacity and, 611
  sarcopenia and, 614–615, 615f
  sensory decline and, 613
  wear and tear and, 611
  weight loss and, 269
Agricultural technology, food production and, 698–699
Agroforestry, 699
Alcohol consumption
  absorption and excretion, 192–193
  adolescents and, 604
  alcohol dehydrogenase, 193–194
  alcohol poisoning, 196, 196t
  alcoholism and, 198, 199t
  binge drinking, 196
  blackout drinking, 196
  blood alcohol levels and, 192–193, 192f, 193t
  bone health and, 422
  breast-feeding and, 570–571
  caffeine and, 196
  calories and, 191, 191t
  cancer and, 197–198
  cardiovascular benefits and risks and, 200, 200f
  central nervous system effects, 196t
  chronic alcohol use effects, 195t, 196–198
  cirrhosis and, 197, 198f
  Dietary Guidelines for Americans and, 43
  diuretic effects, 394
  effects of, 195–196
  ethanol and, 191, 191f
  fatty liver and, 197
  folate (folic acid) and, 327
  heart disease and, 177
  hepatitis and, 197
  liver and, 197
  malnutrition and, 197
  metabolism and, 193–194, 194f
  microsomal ethanol-oxidizing system and, 194
  moderate consumption and, 199–201, 201f
  mortality and, 199, 199f
  obesity and, 197

Alcohol consumption (*continued*)
pregnancy and, 557, 558f
thiamin deficiency and, 312
Alcohol dehydrogenase (ADH), 193–194, 194f
Alcohol poisoning, 196, 196t
Alcohol use disorder, 198, 199t
Alcoholic hepatitis, 197
Alcoholism, 198, 199t
Aldosterone, 399, 399f
Allergens, 89
Allergies. *See* Food allergies
Alli, 277, 278f
Allium vegetables, 379, 380f
Alpha-carotene (α-carotene), 347, 378, 378t
Alpha-linolenic acid, 157, 166, 167
Alpha-tocopherol, 363
Alternative feeding methods, 96, 96f
Alternative sweeteners, 144–147
nonnutritive sweeteners, 145–147, 146t
sugar alcohols, 147
Aluminum, 475
Alveoli (singular, alveolus), 559, 559f
Alzheimer's disease, 617–618
Amenorrhea, 290
American Cancer Society, 61
American Heart Association, 61
American Institute for Cancer Research, 27
American Medical Association, 27
Amino acids
absorption and, 208–209, 209f
amino acid pool, 210, 210f
conditionally essential, 206
deamination and, 214
dipeptides and, 206
essential amino acids, 206, 206f
exercise and, 505–506
fasting and, 258
intolerances and, 223–224
limiting amino acids, 213, 213f
nonessential amino acids, 206, 206f
nonprotein molecule synthesis and, 213
polypeptides and, 206
protein intake and, 215
protein molecules and, 205–206, 206f
protein synthesis and, 105, 211–213
providing energy from, 214–215, 214f
supplements, 228, 228f, 482
transamination and, 206, 206f
tripeptides and, 206
Amniotic fluid, 537f, 538f, 539, 540, 545
Amniotic sac, 537, 537f
Amylase, 77f, 77t, 79,115, 119, 119f
Amylopectin, 117, 117f
Anabolic steroids, 516, 516f, 602
Anabolism, 102–103
Anaerobic glycolysis, 502
Anaerobic metabolism, 125, 502, 503–505, 504f, 505f
Anaphylaxis, proteins and, 209
Androstenedione, 602
Anecdotal claims, nutrition information and, 27, 27f
Anemia
infants and children and, 583
iron and, 448–450. 450f, 514
tobacco smokers and, 327, 327f
vitamin B_6 and, 322
Anencephaly, folate (folic acid) and, 328
Angiotensin II, 398–399, 399f
Animal cell structure, 102
Animal food production, biotechnology and, 678–679
Animal products, proteins from, 204, 205f
Animal studies, 23–24, 24f
Anisakiasis, 649
Anisakis simplex, 643t, 649
Anorexia athletica, 295t, 297–298
Anorexia nervosa
amenorrhea and, 290
behaviors associated with, 289–290, 289f
binge eating and/or purging behaviors, 289t, 290
bone density and, 290
children and, 297
diabetes and, 298–299
diagnostic criteria and, 288–289, 289t
distinguishing characteristics of, 285, 285t
distorted body image and, 289, 289f
exercise and, 290, 290f
men and, 296
physical symptoms and, 290
pregnancy and, 296
psychological issues and, 289
restricting type, 289t, 290
starvation symptoms and, 290
treatment and, 290–291
Antacids, 93
Anthropometric measurements, 64–65, 65f
Antibiotic resistance, genetically modified foods and, 680–681
Antibiotics, food safety and, 657–658
Antibodies, 89, 217
Anti-caking agents, 666t
Antidiuretic hormone (ADH), 392, 392f
Antigens
gastrointestinal tract and, 89
genetically modified foods and, 680
Antioxidants
beta-carotene and, 351
dietary antioxidants, 336
free radicals and, 336
older adults and, 624, 626–628, 628f
oxidative damage and, 336
oxidative stress and, 336, 514
phytochemicals and, 377
pro-oxidants and, 336
supplements, 464–465
vitamin C, 308, 336–337, 337f
vitamin E, 308, 364, 365f, 366
Anus, 86
Apoprotein B, 163
Appetite, external cues and, 241
Aquaculture, 679, 693, 693f
Arachidonic acid, 166
Arginine, as ergogenic aid, 524t
Ariboflavinosis, 315
Arsenic, 475
Arsenic poisoning, 659
Arteries, 99
Arthritis, 65, 617, 617f. *See also* Osteoarthritis
Ascorbic acid. *See* Vitamin C
Aseptic processing, 661, 661f
Aspartame, 146t, 147, 223–224, 224f
Aspergillus flavus, 648, 648f
Assessment, nutritional. *See* Nutritional assessment
Atherosclerosis development, 170–172, 171f
Atherosclerotic plaques, 170
Athletes. *See also* Exercise
anorexia athletica and, 297–298
antioxidant nutrients and oxidative damage, 514
B vitamins and, 512
calcium and vitamin D and, 514–515
carbohydrate, fat, and protein needs, 511–512, 511f
dehydration and, 393, 515–516, 515f
diet and supplement use impact, 530f, 531
eating after exercise, 521–523
eating before exercise, 520–521
eating disorders and, 297–299, 297f, 511
eating during exercise, 521
energy drinks and, 519
ergogenic aids and, 523–531, 524t
female athlete triad and, 298, 298f, 510–511
fluid replacement and, 521
glycogen-restoring regimen and, 521
healthy weight gain and, 511
heat-related illness and, 515–517, 516f
hyponatremia and, 517, 517f
iron deficiency and, 450, 514
making weight and, 510, 510f
maximizing glycogen stores and, 520, 520f
recommended fluid intake for, 517–518, 518f
sports anemia, 514, 514f
teenage athlete issues, 602–603, 603f
vitamin and mineral needs and, 512–515
Atkins diet, 276
Atoms, molecule formation and, 74, 74f
ATP, *See* Adenosine triphosphate
Atrophic gastritis
older adults and, 99, 615
vitamin B_{12} and, 333–334
Atrophy, 494
Attention deficit/hyperactivity disorder (ADHD), 591–592
Avidin, 319
Avoidant/restrictive food intake disorder, 295t

B

Bacillus thuringiensis, 677
Bacteria
Campylobacter jejuni, 643f, 645
Clostridium botulinum, 643t, 646, 646f
Clostridium perfringens, 643t, 646
Escherichia coli, 643t, 644–645
exponential growth and, 644, 644f
genetic engineering and, 211
ground beef and, 645, 645f
heat-resistant spores and, 646
Hepatitis A, 643t, 647–648
Listeria monocytogenes, 643t, 645
pregnancy and, 645
Salmonella, 643t, 644, 644f
Staphylococcus aureus, 643t, 645–646
temperature and bacterial growth, 651, 651f
Vibrio infections, 643t, 645
Bacterial plasmid, 674, 674f
Baked goods, added fats and sugars and, 184
Balance studies, 21, 24f
Barbie dolls, body ideal and, 287f
Bariatric surgery, 278–281, 280f
Basal energy expenditure (BEE), 253
Basal metabolic rate (BMR), 253–255, 255f, 621
Basic Four food guide, 35
Basic Seven food guide, 35

Behavior modification, weight management and, 271–272, 271f
Beriberi, 311, 312, 312f, 695
Beta-alanine supplements, 527
Beta-carotene, 347–349, 348f, 351, 485, 678
Beta-oxidation, 103, 167
Beverages
calories in, 43, 43f
children and teens and, 583, 583f
Bicarbonate, as ergogenic aid, 524t
Bicarbonate supplements, 527
Bifidobacteria, 121
Bile, 84
Bile acid absorption, soluble fiber and, 135, 135f
Binge drinking, 196, 604
Binge eating, 285, 285t, 289, 289t, 290–294, 291t, 292f, 293t, 297
Binge-eating disorder
compensatory behaviors and, 293–294, 294f
complications of, 294
diagnostic criteria for, 293, 293t
distinguishing characteristics of, 285, 285t
pregnancy and, 296
treatment and, 294
Bioaccumulation, 654
Bioavailability
calcium and, 429
folate and, 327
minerals and, 416–417
protein and, 229
vitamins and, 307–308
BioCassava Plus program, 678
Biodiversity, genetically modified foods and, 681
Bioelectric impedance analysis, 247, 248f
Biological value (BV), 229, 229f
Biotechnology
animal food production and, 678–679
aquaculture and, 670
bacteria creation and, 211
crop yields and, 677
disease and, 679
DNA structure and, 671–672, 672f
food production and, 698–699
food quality and processing and, 678
genes to proteins to traits, 672–673, 673f
genetic engineering and, 671, 671t
genetic modification and, 675–676
genetically modified foods, 679–683
hybridization and, 675, 675f
methods of, 673–675
modern techniques and, 675, 676f
mutations and, 675
nutritional quality and, 678, 678f
passing traits from parent to offspring, 673
pesticides and, 656
plasmids and, 674, 674f
recombinant DNA and, 674, 674f
restriction enzymes and, 674
selective breeding techniques and, 675
traditional breeding technology and, 675
transgenic organisms and, 675
Biotin
deficiency and, 319–320
in the diet, 319
functions in body and, 319
life cycle and, 320
pregnancy and, 320
raw eggs and, 319, 319f
recommended intake and, 320
toxicity and, 320
Bisphenol A, plastic containers and, 664, 664f
Bisphosphonates, 426
Blackout drinking, 196
Blindness
diabetes mellitus and, 130
vitamin A and, 354
Blood clotting, vitamin K and, 367–368, 368f
Blood pressure
assessing, 401, 401f
calcium and, 429
dietary patterns and, 406–407, 406f–407f
diet's affects on, 402–403
food labels and, 409–410, 410t
hypertension and, 401–403
lifestyle choices and, 402, 420t
regulation of, 398–399, 399f
sodium intake and, 403, 410
water intake and, 388
Blood vessels, nutrient delivery and, 99–100, 100f
BOD POD measures, 247, 248f
Body cells, nutrient delivery and, 101, 102f
Body composition, 246–248
aging and, 614–615
assessment of, 247–248, 248f
bioelectric impedance analysis and, 247
dilution methods and, 247–248
dual-energy X-ray absorptiometry and, 247
exercise and, 494, 495f
fat-free mass and, 246
lean body mass and, 246
life cycle changes and, 246f, 247
muscle mass and, 246f, 247
skinfold thickness measurements and, 247
underwater weighing and, 247
visceral fat and, 247
water and air displacement and, 247
Body dysmorphic disorder, 295t
Body fat
insulin and, 264
leptin and, 264–266, 265f
location of and health risks, 248–249, 249f
regulation of, 264–265
Body image and ideal
anorexia nervosa and, 289, 289f
bulimia nervosa and, 291
changing female ideal, 288, 288f
eating disorders and, 287–288, 288t
mass media and, 287, 287f
modern America and, 287–288
through history, 286–287, 287f
Body mass index (BMI), 244–246
bone density and, 424
children and, 581–582, 581f
excess weight risks and, 268–269, 268f
healthy range and, 245, 245f
limitations of, 245–246
muscle mass and, 246f, 247
Body measurements, 64–65, 65f
Body processes, nutrients and, 11f, 12
Body size and shape, 262–267
adaptive thermogenesis and, 267
body fat regulation and, 264–265
brown adipose tissue and, 267
energy expenditure and physical activity, 267
food intake regulation and, 264
futile cycling and, 267
genes *vs.* environment, 262–263, 263f
NEAT in obese and lean individuals, 257, 267f
obesity genes and, 262, 262f
satiety and, 264
set point and, 263–264
thrifty metabolism and, 265–267
Body structure, nutrients and, 11f, 12
Body temperature, water and, 386–387, 387f
Body weight. *See also* Obesity; Underweight; Weight management
basal metabolism and, 254
body composition and, 246–248
body fat location and risks, 248–249, 249f
body mass index and, 244–246, 245f
cancer and, 243
cardiovascular disease and, 242
diabetes and, 242
dietary fat and, 178
excess body fat and health, 242–244, 243f
fasting and, 257–258
feasting and, 256–257, 256f
food supply and, 241
gallbladder disease and, 242–243
healthy weight guidelines, 244–249
joint disorders and, 243–244
metabolic syndrome and, 242
obesity rates, 240, 240f
physical activity and, 241–242, 242f
portion sizes and, 241, 241f
pregnancy and, 538f, 539–540, 539f, 539t
psychological and social problems and, 244
set point and, 263–264
sleep apnea and, 243
social changes and, 241
subcutaneous fat and, 248–249, 249f
underweight and, 244
visceral fat and, 248–249, 249f
weight cycling, 270, 270f
Bomb calorimeter, 250–251, 251f
Bone health. *See also* Osteoporosis
alcohol use and, 422
anorexia nervosa and, 290
body mass index and, 424
bone remodeling, 411, 411f
bone resorption and, 420
bone structure and remodeling and, 418–420, 419f
cortical or compact bone, 419
diet and, 424
genetics and, 422
hydroxyapatite and, 418
infants and children and, 583
life cycle and, 420
osteoblasts and, 420
osteoclasts and, 420
peak bone mass and, 420
physical activity and, 422–424, 496
postmenopausal bone loss, 422
protein excess and, 220
smoking and, 422
space flight and, 423
trabecular or spongy bone, 419
vitamin D and, 358–359
Boost (nutritional product), 630
Boron, 475
Bottle-feeding, 571–573
drug transmission and, 572
feeding requirements and, 572

Bottle-feeding (*continued*)
genetic abnormalities and, 572
infant size and, 572
nursing bottle syndrome and, 573, 573f
nutritional composition and, 571–572, 571t
positioning child and, 573
practical aspects of, 572–573, 572f
recommendations for, 572
sleeping and, 573
Bottled water, 395
Bovine somatotropin, 657–658, 659f
Bovine spongiform encephalopathy (BSE), 649–650
Bowel health, fiber and, 135–136
Bran, 111, 118
Branched-chain amino acid supplements, 528
Branched-chain amino acids, as ergogenic aid, 524t
Breakfast, 6, 7f
Breakfast cereals, fortification and, 305, 305f
Breast-feeding, 568–571
benefits of, 569–570, 569f
caffeine and alcohol and, 570–571
facial muscles and, 570
feeding requirements and, 570
immune factors and, 570
lactalbumin and, 569
lactose and, 569
lipids and, 569
nutritional advantages and, 568–569
nutritional composition and, 568–569, 571t
practical aspects of, 570–571
pumped breast milk, 571, 571f
termination of, 570
vitamin D supplementation and, 362
Bromine, 475
Brown adipose tissue, 267
Brush border, 83
Bt corn, 677, 677f
Bulimia nervosa, 291–293
behaviors associated with, 292, 292f
binge eating and, 292
body image and, 291
compensatory behaviors and, 292
diabetes and, 298–299
diagnostic criteria for, 291, 291t
distinguishing characteristics of, 285, 285t
physical complications and, 292–293
pregnancy and, 296
psychological issues and, 291
purging behavior and, 292
social isolation and, 291
treatment and, 293
Bulking up, teenage athletes and, 602

C

Cadmium, 475
Cadmium poisoning, 659
Caffeine
alcohol consumption and, 196
breast-feeding and, 570–571
as diuretic, 394
as ergogenic aid, 524t, 530
hyperactivity in children and, 591–592
pregnancy and, 556–557
Calcitonin, calcium homeostasis and, 430
Calcium, 427–434, 439t
absorption and, 428, 428f
adolescents and, 598
age-related bone loss and, 421–422
athletes and, 514–515
bioavailability of, 429
blood pressure regulation and, 429
calcitonin and, 430
deficiency and, 430
in the diet, 427–428, 427f
dietary sources of, 431–433, 431f
digestive tract and, 428–429
excessive, 433–434
food labels and, 432
functions in body, 429–430
infants and children and, 583
iron absorption and, 446
kidney stones and, 433
lactose intolerance and, 120–121
life cycle and, 428–429, 430–431
medications and, 429
meeting needs and, 431–433
milk-alkali syndrome and, 433
milk and, 431, 431f
muscle contraction and, 429
MyPlate food groups and, 427–428, 427f
nerve transmission and, 429
older adults and, 624
osteoporosis risk and, 424
parathyroid hormone and, 430
pregnancy and, 545–546
recommended intake and, 430–431
regulatory mechanisms and, 429–430, 430f
regulatory roles of, 429
supplements and, 426, 433
vitamin D deficiency and, 429
yogurt and, 432
Calories
bomb calorimeter and, 250–251, 251f
caloric restriction and life span, 608–609
carbohydrates and, 134, 134f
children and, 578–579
Choice (Exchange) Lists and, 251, 253t
consumption of, 250–253
determining food energy and, 250–251, 251f
expenditure of, 253–256
food labels and, 252
in foods, 9, 9f
MyPlate and, 48, 48t
weight management and, 42
Calories Don't Count, 276
Campylobacter jejuni, 643t, 645
Cancer
aging and, 616, 616f
cancer cells, 136–137, 136f
carcinogens and, 136
dietary fat and, 177–178
excess body weight and, 243
folate (folic acid) and, 328–329
iron intake and, 452–453
malignancy and, 136
mold toxin and, 648, 648f
mutations and, 136
physical activity and, 495–496
protein excess and, 223
selenium deficiency and, 462–463
tumor initiators and, 137
tumor promoters and, 137
vitamin C and, 339
vitamin D and, 359
Canola oil, 235
Capillaries, nutrient absorption and, 99
Capsaicin, 378t
Carbohydrates
added sugars and, 111, 112–114, 114f
alternative sweeteners and, 144–147, 146t
athlete requirements and, 511–512, 511f
in the body, 122–127
bowel health and, 135–136
calculating energy percentage, 138t
calorie intake and, 134, 134f
carbohydrate counting, 130
carbohydrate loading, 117, 520, 520f
carbohydrate recommendations, 137–147
colon cancer and, 136–137, 136f
comparing fiber content, 139t
complex carbohydrates, 116–118, 117f
dental caries and, 133–134, 134f
diabetes mellitus and, 128–132, 128f
digestion and absorption, 119, 119f
in digestive tract, 118–122
disaccharides, 115–116, 115f
during exercise, 521
fat synthesis and, 257, 258f
fiber and, 118, 118f, 121–122, 135–137, 136f
functions of, 10, 10f, 123
glucose and energy, 125–126
glucose delivery and, 123–125
glycogen, 116–117, 117f
health and, 128–137
healthy carbohydrates, 141
heart disease and, 135, 135f
high-fructose corn syrup and, 112–113
hypoglycemia and, 132–133
infants and children and, 564, 582
ingredient lists and, 144–145
ketone formation and, 127
lactose intolerance and, 120–121, 120f
limiting added sugars, 140–141, 141f
low intake of, 126–127, 127f
monosaccharides, 114–115, 115f
more whole grains, fruits, and vegetables and, 140
MyPlate and, 139, 140f
older adults and, 622
oligosaccharides, 116
in our food, 110–113, 110f
pregnancy and, 544
recommendations for, 137–147
refinement and, 110–111, 142
simple carbohydrates, 114–116
starches, 117, 117f
sugar chains and, 116, 116f
sugar consumption and, 111
supplements, 481–482
total carbohydrates, 137–139
translating into healthy diets, 139–141
types of, 114–118, 139
using choice (exchange) lists and, 138t
using food labels and, 142–144, 143f
weight management and, 134, 134f
whole-grain products and, 111, 111f
Carcinogens, 136, 378
Cardiopulmonary endurance, 492–493, 493f
Cardiovascular/circulatory system, 75t
Cardiovascular disease
atherosclerosis and, 170–172, 171f
folate (folic acid) and, 328
heart disease risk factors, 172–177, 172t
lipids and, 170–177
obesity and, 242

vitamin B_6 and, 324, 324f
vitamin C and, 338–339
Cardiovascular system
aging and, 614
alcohol consumption and, 200, 200f
heart and blood vessels, 99–100, 100f
hepatic portal circulation, 100–101, 101r
nutrient delivery and, 99–101, 100f
physical activity and, 495
Carnitine, 339, 505, 524t
Carnitine supplements, 484, 530
Carotenoids, 347–349, 348f
as antioxidants, 377
macular degeneration and, 379
sources and effects, 378–379, 378t
supplements, 357t, 485, 485f
toxicity, 356–357, 356f
Carpal tunnel syndrome, 325
Case-control studies, 21
Cash crops, 699
Catabolism, 102–103
Cataracts, 613, 613f
Catechins, 378t
Celiac disease, 89, 223
Cell cultures, 24, 25f
Cell differentiation, vitamin A and, 347, 350–351
Cell membrane protection, 364–365
Cell membranes, nutrients entering, 101
Cells, tissue and organ formation and, 74, 74f
Cellular respiration
ATP production and, 103–104, 104f
glucose and, 125, 126f
Cellular studies, 24, 25f
Ceruloplasmin, 459
Cesarean section, 539
Cheese, production of, 678, 678f
Chemical bonds, 74, 74f
Chewing, 79
Chewing and spitting disorder, 295t
Child and Adult Care Food Program, 632t, 706t
Childhood obesity, 592–596
changing behavior and, 596
fast food and, 594, 594f, 595t
food choices and, 579, 579f
increasing activity and, 596, 596f
psychological and social problems and, 244
reducing incidence of, 595
reducing intake and, 595
television affects and, 592–594, 594f
weight management programs and, 595
Children. *See also* Childhood obesity
anemia and, 583
attention deficit/hyperactivity disorder and, 591–592
beverage choices and, 582, 583f
body mass index and, 581–582, 581f
bone health and, 583
calcium and, 583
calorie intake and, 578–579
carbohydrate recommendations and, 582
cholesterol and, 580, 580f
day care or school meals and, 589, 589f
dental caries and, 591
eating disorders and, 296–297
eating environment and, 589, 589f
eating habits and, 578–579, 579f
energy and protein needs and, 582, 582f
fluoride and, 472
food allergies and intolerances and, 590–591
food jags and, 587
health snacks fand, 589t
healthy eating habits and, 580, 586–589, 587f
heart disease and, 580
hypertension and, 580
hypothermia and, 515
infection risk and, 687–688, 688f
iron and, 583
lead toxicity and, 592
malnutrition and, 687
meal and snack patterns and, 588, 588t
meeting nutrient needs and, 583–589
micronutrients and, 582–583
monitoring growth and, 581–582, 581f
nutrient needs and, 582–583
physical activity recommendations and, 500, 500f
protein-energy malnutrition and, 693, 693f
social isolation and, 579, 579f
stunting and, 687, 687f
sugar in diet and, 591, 591f
teeth brushing and, 591
type 2 diabetes and, 579
vitamin A deficiency and, 351, 695
vitamin and mineral supplements and, 587–588
vitamin D and, 583
water and electrolytes and, 582
Chinese restaurant syndrome, 224
Chlordane, 659
Chloride, 396–400, 400t
deficiency and, 399–400
fluid balance and, 397
function in body, 397–398
homeostasis and, 398
muscle contraction and, 397–398
nerve conduction and, 397–398
in our food, 396–397, 396f
recommended intakes and, 403–406
Choice (Exchange) Lists
estimating carbohydrate content and, 138, 138t
estimating energy content and, 251, 253t
estimating fat content and, 180, 180t
estimating protein content and, 227, 227t
meal planning and, 60, 61f, 61t
Cholecalciferol, 357
Cholecystokinin (CCK), 78t, 84, 264
Cholesterol
alcohol consumption and, 200
body structure and, 166
cell entry and, 163
children and, 580, 580f
dietary recommendations and, 178–181
egg consumption and, 182–184, 185f
elimination and, 165
food labeling and, 186, 186f
genetic disease and, 164
heart disease and, 173, 173f
high-density lipoproteins and, 165
oxidized LDL cholesterol, 170
soluble fiber and, 135, 135f
structure and sources, 159, 160f
vitamin C and, 339
Choline, 339–341, 340t
excess, 341
functions in body, 339–341
MyPlate and, 341, 341f
supplements and, 339
Chondroitin supplements, 484, 484f
Chromium, 454t, 469–470, 474t
absorption of, 469
deficiency and, 469–470
in the diet, 469
as ergogenic aid, 524t
functions in body, 469
insulin function and, 469, 469f
pregnancy and, 470
recommended intake and, 470
supplements and, 470, 470f
toxicity and, 470
Chylomicrons, 162
Chyme, 81, 82
Cigarette smoking. *See* Smoking
Cirrhosis, alcohol and, 197, 198f
Cis fatty acids, 156f, 157
Citric acid cycle, 104, 125
Clinical trials, 21
Clostridium botulinum, 643t, 646, 646f
Clostridium perfringens, 643t, 646
Coagulation, 366
Cobalamin, 333
Cocaine, 558–559
Coconut oil, 176
Cod liver oil, 584
Coenzyme A (CoA), 125
Coenzyme functions, vitamin B_6 and, 322, 323f
Coenzyme Q10, 484, 524t
Coenzyme supplements, 484
Coenzymes, 103, 308, 308f
Cofactor, 409, 410f
Cognition, aging and, 617–618
Cold pasteurization, 663–664, 663f
Colic, 568
Collagen synthesis, vitamin C and, 336, 336f
Colon, 86
Colon cancer, 87, 136–137, 136f
Color additives, 665–666, 666f
Colostrum, 559, 569
Commodity Supplemental Food Program (CSFP), 632t, 706t
Common cold
vitamin C supplements and, 338, 339f
zinc lozenges and, 458, 458f
Compact bone, 419
Complete dietary proteins, 228
Complex carbohydrates, 116–118, 117f
Compression of morbidity, 610, 610f
Computerized diet analysis, 64, 65f
Conception, 536
Conditionally essential amino acids, 206
Congregate meals, 629–630, 630f
Constipation
fiber and, 136
nutritional consequences and, 95, 95t
pregnancy and, 541
Consumer safety, genetically modified foods and, 680–681
Contamination sources, food, 636, 637f
Contractile proteins, 217–218
Control groups, human intervention studies and, 21
Cooking safety, 652, 653t
Copper, 454t, 458–460, 474t
absorption of, 459, 459f
ceruloplasmin and, 459

Copper (*continued*)
contaminated water supplies and, 460
deficiency and, 460
in the diet, 458, 459f
in digestive tract, 459
functions in body, 459
immune response and, 460
kinky hair disease and, 458
life cycle and, 460
Menkes disease and, 458
pregnancy and, 460
preterm infants and, 460
recommended intake and, 460
skeletal abnormalities and, 460
toxicity and, 460
zinc antagonism and, 459, 459f
Corn-based diets, niacin and, 318, 318f
Correlations, observational studies and, 21
Cortical bone, 419
Creatine, as ergogenic aid, 524t
Creatine phosphate, 503
Creatine supplements, 484, 527, 527f
Creatinine, 602
Cretinism, 467, 694–695
Crib death, 558
Critical control points, 639t, 640, 641f
Critical periods, 556, 556f, 568
Crop yields, biotechnology and, 677
Cross-breeding, 675
Cross-contamination, food, 636
Cross-fertilization, 675, 675f
Cross-pollination, 675, 675f
Cruciferous vegetables, 379, 380f
Crucifers, 379
Cryptosporidium, 649
Cryptosporidium parvum, 643t
Cultural considerations, food choices and, 5, 5f
Cultural practices, undernutrition and hunger and, 691
Curcumin, 378t
Customer contamination, food safety and, 641–642
Cyclamate, 147
Cycle of poverty, 705, 705f
Cycle of undernutrition, 686–687, 686f
Cystic fibrosis, vitamin E deficiency and, 365
Cytosol, 101

D

Daily reference values (DRVs), 52
Daily values, food labels and, 52–54, 53f
Dark skin pigmentation, vitamin D and, 361, 361f
DASH dietary patterns, heart disease risk and, 173
DASH eating plan, 406–407, 406f–407f
DASH trial, 404–405
Day care meals, children and, 589, 589f
Deamination, 103, 214
Dehydration
exercise and, 515–516, 515f
infancy and, 565
levels of, 392–393
older adults and, 622
risk groups and, 393, 393f
Dehydration reactions, 116, 116f
Dehydroepiandrosterone (DHEA)
aging and, 616
as ergogenic aid, 524t
supplements, 483–484, 483f
Delaney Clause (Food Additives Amendment), 668
Dementia, 617–618
Denaturation, proteins and, 207–208, 208f
Dental caries, 133–134, 134f, 591
Dental pain, digestive problems and, 95t
Dependent living, older adults and, 620, 620f
Depletion-repletion studies, 21
Depression, older adults and, 621
DHA-fortified infant formulas, 565
Diabetes
acid-base balance and, 218
adolescents and, 129, 129f
alcohol consumption and, 200
carbohydrates and, 128–132, 128f
children and, 579
diet and, 130–131
eating disorders and, 298–299
excess weight and, 242
exercise and, 131
gestational diabetes, 129, 543
hypertension and, 402
immediate symptoms and, 130
impaired glucose tolerance and, 129
insulin and, 132–133
iron and, 452
long-term complications and, 130, 130f
management of, 130–132, 131f
medication and, 131–132
metabolic syndrome and, 129
nutritional assessment and, 65
physical activity and, 495
prediabetes, 129
Type 1 diabetes, 128
Type 2 diabetes, 128–129
Diabetes mellitus, 128. *See* Diabetes
Diabulimia (insulin misuse), 295t, 299
Diacylglycerol, 154
Diarrhea, 92– 95, 95t, 393
Dicumarol, 369
Diet
balancing food choices and, 17–18, 18f
calcium in, 427–428, 427f
diabetes mellitus and, 130–131
diet history, 64
diet-induced thermogenesis, 256
dietary antioxidants, 336
fad *vs.* healthy, 274t
food groups and, 275
genetic makeup and, 13–14, 14f
healthy diet choice, 14–18
heart disease risk and, 173–175, 174f–175f
high-fiber diets, 134
high-protein diets, 221, 277
hypertension and, 402–403
intake estimation and, 62–63
low-carbohydrate diets, 134, 276–277, 276f
low-fat diets, 276, 276f
macronutrient proportion and, 276–277
magnesium and, 436
minerals in, 414–416
moderation and, 18
nutrient density and, 14–16, 17f
osteoporosis risk and, 424
phosphorus and, 434
prepackaged meals and formulas and, 275, 275f
protein sources in, 204, 205f
protein-sparing modified fast, 275
trace minerals in, 444
variety and, 16–17
vegetarian diets, 232–236
very-low-calorie diets, 275–276
weight-loss diets, 273t
yo-yo dieting, 270, 270f
zinc and, 454
Dietary fat, body fat and, 257, 257f
Dietary folate equivalents (DFEs), 329, 329t
Dietary Goals for the United States, 35
Dietary Guidelines for Americans, 35, 40–45
balance calories with activity, 43, 43t
follow a healthy eating pattern, 41–43, 41t, 42f, 43t
healthy eating patterns, 41–43, 41t, 42f
key recommendations and, 41t
limit added sugars, saturated fat, and sodium, 43t, 44
meet food group recommendations, 43
purpose of, 40–41
support from all segments of society, 44–45
The Guidelines, 41t
weight and exercise recommendations and, 44f
Dietary reference intakes (DRIs), 37–40
all population groups and, 37, 37f
applications of, 40
energy intake recommendations, 39–40, 40f
nutrient intake recommendations, 38–39, 38f
Dietary supplements. *See also* Herbal supplements
amino acids and, 482
antioxidants and, 464–465
athletic performance and, 523–531
building muscle and, 525–526, 526f
calcium and, 426, 433
carbohydrates and, 481–482
carnitine and, 484
carotenoids and, 485, 485f
chondroitin and, 484, 484f
coenzyme Q and, 484
coenzymes and, 484
creatine and, 484
daily values and, 372
dehydroepiandrosterone (DHEA) and, 483–484, 483f
eliminating malnutrition and, 702
enzymes and, 483
ergogenic aids, 523–531, 524t
flavonoids and, 485
glucosamine and, 484, 484f
Good Manufacturing Practices for, 479
groups recommended for, 371, 371t
hormones and, 483–484
inositol and, 485
iron and, 451, 451f, 453
labeling and, 55–59, 479, 481f
magnesium and, 438
medical history and, 373
medications and, 371
melatonin and, 483, 483f
minerals and, 416
niacin and, 319
nutrient supplements, 481–482
older adults and, 626–628, 628f
omega-3 fatty acids and, 482, 482f
osteoporosis and, 425–426
phytochemicals and, 383, 485
pregnancy and, 549–550, 551f
proteins and, 482

regulation of, 479
riboflavin and, 315
risks and, 371
SAM-e and, 484
selenium and, 463–464
structural and regulatory molecules and, 484–485, 484f
substances made in body, 482–485
suggestions regarding, 373
supplemental facts panel and, 372
thiamin and, 313, 313t
types of, 479
varied diet and, 371
vitamin B_6 and, 325
vitamin B_{12} and, 334
vitamin C and, 338–339
vitamin D and, 362
vitamin E and, 363–364
vitamin K and, 368
vitamin/mineral supplements, 305, 370–373, 481
water-soluble vitamins and, 313t
weight loss and, 277–278, 480t
zinc and, 457–458
Digestible indispensable amino acid score (DIAAS), 230
Digestion, 78–86. *See also* Digestive tract
alcohol and, 192–193
carbohydrates and, 119, 119f
digestive hormones, 78, 78t
digestive system and, 75
esophagus and, 80, 80f
large intestine and, 86
mouth and, 79
pharynx and, 79–80, 79f
proteins and, 208, 208f
small intestine and, 83–86
stomach and, 80–83
vitamins and, 307–308
water and, 390
Digestive problems
antacids and, 93
diarrhea and constipation, 92, 95
enteral or tube-feeding and, 96
heartburn and GERD, 91–92, 92f
nutritional consequences and, 95t
nutritional effects of, 98
pancreatic and gallbladder problems, 92
peptic ulcers, 92, 94
total parenteral nutrition and, 96, 96f
Digestive secretions, 77, 77f
Digestive tract, 75–78, 75t
aging and, 99
calcium in, 428–429, 428f
copper in, 459
digestive enzymes and, 77, 77t
digestive secretions and, 77
fibers in, 118–122
folate (folic acid) in, 326–327
gastrointestinal activity regulation and, 78, 78t
immature infant and, 97–98
iron in, 445–446
lipids in, 160–161, 161f
magnesium in, 436
major functions of, 75
organs of, 76–77, 76f
phosphorus in, 325
pregnancy and, 96–97
throughout life, 96–99, 97f
vitamin A and, 348
vitamin B_{12} and, 332, 332f
vitamins in, 307–308, 307f
zinc in, 454–455
Diglycerides, 154
Dipeptides, 206
Direct calorimetry, 259
Direct food additives, 665
Disaccharides, 115–116, 115f
Disease resistance, biotechnology and, 677, 677f, 679
Dispensable amino acids, 206, 206f
Diverticula, 95, 135
Diverticulosis, 135, 136f
DNA ligases, 212
DNA structure, 671–672, 672f
Docosahexaenoic acid (DHA), 157, 166
Double-bind study, experiments and, 29
Doubly labeled water technique, 259
Dowager's hump, 420, 420f
Down syndrome, 555, 555f
Dry beriberi, 312
Dry mouth, 95t
Dual-energy X-ray absorptiometry (DXA), 247, 248f

E

Eating disorders
anorexia nervosa, 288–291
athletes and, 297–298, 297f, 511
binge-eating disorder, 293–294
body ideal and, 286–288, 287f, 288f
body image and, 287–288, 288t
bulimia nervosa and, 291–293
causes of, 285–288, 286f
children and, 296–297
diabetes and, 298–299
distinguishing among, 285, 285t
genetics and, 286
getting help for friend or family member, 299–300, 300t
less common disorders and, 294, 294t
in men, 294–296, 296f
pregnancy and, 296
psychological characteristics and, 286
recognizing risk and, 299
reducing prevalence of, 300
self-esteem and, 286
sociocultural factors and, 286–287
teenagers and, 602
Eating environment, children and, 589, 589f
Eating patterns, 6, 6f
Echinacea, 487f, 488t, 489
Eclampsia, 542–543
Economic limitations, older adults and, 629–630
Edema, pregnancy and, 541, 541f
Education, nutrition, 708
Egg consumption, dietary cholesterol and, 182–184, 185f
Eggs, raw, 319, 319f
Eicosanoids, 167
Eicosapentaenoic acid (EPA), 157
Elderly. *See* Older adults
Electrolytes, 396–400, 400t
balance regulation and, 398–399
deficiency and, 399–400
fluid balance and, 297f, 397
function in body, 397–398
hypertension and, 401–403
infants and children and, 582
muscle contraction and, 397–398
nerve conduction and, 397–398, 398f
in our food, 396–397, 396f
potassium homeostasis and, 399
pregnancy and, 545
recommended intakes and, 403–406
sodium and chloride homeostasis and, 398–399
toxicity and, 400
Electron transport chain, 104, 104f, 125
Electrons, 104, 386
Elimination diets, 590–591
Ellagic acid, 378t
Embryo, 536
Emergency food aid, 697, 697f
Emergency Food Assistance Program, 706t
Emotional factors, food choices and, 5
Emotions, gastric emptying and, 83
Empty calories, 49–51, 51f
Emulsifiers, 158, 158f, 666t
Endocrine system, 75t
Endorphins, physical activity and, 496–497
Endosperm, 111
Endurance enhancement, ergogenic aids and, 529–530
Energy balance, 250–258, 250f
basal metabolism and, 253–255, 255f
carbohydrates and proteins and, 257, 258f
dietary fat and, 257, 257f
energy consumption and, 250–253
energy expenditure and, 253–256
energy storage and, 256–258
fasting and weight loss, 257–258
feasting and weight gain, 256–257
nonexercise activity thermogenesis and, 255
physical activity and, 255–256, 256f, 267, 496, 496f
sources of energy in body, 257, 257t
thermic effect of food, 256
total energy expenditure, 253
vitamins and, 308, 308f
Energy drinks, 196, 519
Energy intake
acceptable macronutrient distribution ranges (ADMRs), 39, 40f
estimated energy requirements (EERs), 39, 40f
recommendations, 39–40
reduction methods, 273–277
weight-management program and, 270–271
Energy requirements, 258–262
activity level and, 509, 509f
adolescents and, 598, 598f
direct calorimetry and, 259
doubly labeled water technique and, 259
EER equations and, 260–261, 261f
estimated energy requirements (EERs), 258–262, 261t
indirect calorimetry and, 259, 259f
infants and children and, 563–564, 563f, 582, 582f
lactation and, 560–561, 561f
life cycle and, 262
MyPlate and, 48, 48t
older adults and, 632–633
physical activity and, 259–260, 260f, 508–511, 509t
pregnancy and, 543–544, 543f
weight and, 510

Energy-yielding nutrients, 9–10
Enriched grains, 8, 111, 111f
Ensure (dietary supplement), 630
Enteral feeding, 96
Environment impact, aging and, 611–612, 612f
Environmental factors, body size and shape and, 262–263, 263f
Environmental Protection Agency (EPA), 683
Environmental resources, undernutrition and hunger and, 691
Environmental toxins, pregnancy and, 556
Enzyme supplements, 483
Enzymes, digestion and, 77, 77f, 77t, 217
Ephedra, 278
Epidemiology, 20–21, 20f, 22
Epiglottis, 79
Epinephrine, 125
Epithelial tissue, vitamin A and, 350–351
Ergocalciferol, 357
Ergogenic aids, 523–531, 524t
  building muscle and, 525–526, 526f
  endurance enhancement and, 529–530
  evaluating benefits and risks, 523, 523t
  short, intense activities and, 527–528
  vitamin and mineral supplements, 523–525
Erythropoietin (EPO), 528–530
Escherichia coli, 643t, 644–645
Esophagus, digestion and absorption and, 80, 80f
Essential amino acids, 206, 206f
Essential fatty acids
  body processes and, 166, 166f
  deficiency and, 166–167
  requirements and, 179
Estimated average requirements (EARs), 38, 38f
Estimated energy requirements (EERs), 39, 40f, 258–262, 261t
Ethanol, 191, 191f
Ethical concerns, scientific studies and, 24–25
Ethnic food choices, 16
Evaporative losses, water and, 391
Excess body fat, health and, 242–244, 243f
Excretion
  alcohol and, 192–193
  vitamins and, 308
Exercise. *See also* Athletes; Physical activity
  aerobic exercise, 492–493, 493f
  aerobic metabolism and, 504f, 505, 505f
  anaerobic metabolism and, 503–505, 504f, 505f
  anorexia nervosa and, 290, 290f
  body composition and, 494, 495f
  carnitine and, 505
  childhood obesity and, 596, 596f
  creatine phosphate and, 503
  dehydration and, 515–516, 515f
  diabetes mellitus and, 131
  diet and supplement impact and, 530f, 531
  Dietary Guidelines for Americans and, 42, 42f
  duration and metabolism, 502–506
  eating after, 521–523
  eating before, 520–521
  eating during, 521
  energy drinks and, 519
  ergogenic aids and, 523–531, 524t
  fatigue and, 506
  fluid intake and, 517–518, 518f
  fluid replacement and, 521
  gastric emptying and, 83
  glycogen depletion and, 507
  glycogen-restoring regimen and, 521
  heat-related illnesses and, 515–517, 516f
  hyponatremia and, 517, 517f
  hypothermia and, 515
  instant energy and, 503, 503f
  intensity and metabolism, 506–507, 507f
  lactic acid and, 503
  long-term energy and, 503f, 505
  low-intensity exercise and, 506–507
  maximizing glycogen stores and, 520, 520f
  muscle-strengthening, 493, 493f
  older adults and, 628–629, 628t
  oxygen delivery to muscles and, 502–503, 502f
  pregnancy and, 540, 540t
  protein needs and, 228
  protein use and, 505–506
  short-term energy and, 503–505
  sports bars and, 422
  training and aerobic capacity, 507–508, 508f
  weight-management program and, 271
Expanded Food and Nutrition Education Program (EFNEP), 706t, 708
Experimental control, nutrition information and, 29
Experimental groups, human intervention studies and, 21
Extracellular fluids, 388

F

Facilitated diffusion, small intestine and, 85
Fad diets, 273t
Failure to thrive, 568
Familial hypercholesterolemia, 164
Family history, nutritional assessment and, 65, 65f
Family meals, children and, 589, 589f
Famine, 689–690, 689f
Fast foods
  childhood obesity and, 594, 594f, 595t
  healthy choices and, 16
Fasting
  fat storage during, 167–169, 169f
  weight loss and, 257–258
Fat. *See also* Lipids
  athlete requirements and, 511–512, 511f
  calculating percentage of energy from, 180t
  cancer and, 177–178
  Dietary Guidelines for Americans and, 43
  dietary recommendations and, 178–187
  essential fatty acid needs, 179
  fasting and, 169
  fat replacers, 186–187, 187f
  feasting and, 169
  food labels and, 184–186, 185f
  health affects of, 153, 153f
  healthy fats, 180–181, 183t
  infants and, 564
  meats and, 184
  MyPlate and, 48, 49f, 181–184, 182f
  obesity and, 178
  older adults and, 622
  pregnancy and, 544
  reduced-fat foods, 186–187
  sources in our diet, 152–153, 152f
  storage and retrieval, 167–169, 169f
  total fat requirements and, 179–180
  using choice (exchange) lists and, 180t
Fat burners, 278
Fat-free mass, 246
Fat replacers, 186–187, 187f
Fat-soluble vitamins, 304, 304f, 370t
  in our diet, 346, 346f
  Vitamin A, 346–357
  vitamin D, 357–362
  vitamin E, 363–366
  vitamin K, 366–371
Fatigue, exercise intensity and, 506
Fatty acids. *See* Triglycerides and fatty acids
Fatty liver, 197
Feasting
  fat storage during, 169, 169f
  weight gain and, 256–257, 256f
Fecal losses, water and, 391
Feces, 75
Female athlete triad, 295t, 298, 298f, 510–511, 602
Fermentable fiber, 135
Fermentation, 660
Ferritin, iron storage and, 446
Fertility rates, education and, 698, 698f
Fertilization, 536
Fetal alcohol spectrum disorders (FASDs), 557
Fetal alcohol syndrome (FAS), 557, 558f
Fiber
  bowel health and, 135–136
  cholesterol and, 135, 135f
  colon cancer and, 136–137, 136f
  comparing fiber content, 139t
  in digestive tract, 121–122
  diverticulosis and, 135, 136f
  function of, 10
  GI function and, 121, 121f
  insoluble fiber, 118
  intestinal gas and, 121–122
  microbiota promotion and, 121
  nutrient absorption and, 122, 122f
  older adults and, 622
  recommendations for, 139
  soluble fiber, 118
  sources of, 118, 118f
Fibrin, 367, 368f
Field gleaning, 707, 707f
Fight Bac! educational campaign, 650, 651f
Fish consumption, pregnancy and, 659, 659f
Fish farming, 670
Fitness, physical activity and, 492–494
Flavin adenine dinucleotide (FAD), 314–315
Flavin mononucleotide (FMN), 314–315
Flavonoids
  fruits and vegetables and, 381, 382f
  sources and effects, 378t, 379
  supplements, 485
Flavors, additives and, 665–666, 666t
Flavr Savr tomato, 678
Flaxseed, 235
Flexibility, 494, 494f
Fluid balance, 218, 397, 397f
Fluid needs
  dehydration and exercise, 515–516, 515f
  heat-related illnesses and, 515–517, 516f
  hyponatremia and, 517, 517f
  physical activity and, 515–519
  recommended intake for exercise, 517–518, 518f
Fluid pressure, water movement and, 388, 389f

Fluoride, 470–473, 474t
breast milk and, 472
deficiency and, 472
in the diet, 470, 470f
fluorosis and, 472, 473f
functions in body, 472
infants and, 566
life cycle and, 472
public drinking water and, 472
recommended intake and, 472
tooth decay and, 471–472
toxicity and, 472
Fluorosis, 472, 473f
Folate (folic acid), 325–331
alcohol and, 327
anemia and, 327, 327f
anencephaly and, 328
bioavailability of, 327
cancer and, 328–329
cardiovascular disease and, 328
deficiency and, 327, 695
in the diet, 326–327
dietary folate equivalents and, 329, 329t
in digestive tract, 326–327
folate monoglutamate, 326f
folate polyglutamate, 326–327
food labels and, 329
fortified foods and, 329, 329t
functions in body, 327
heart disease and, 177
life cycle and, 327
macrocytic anemia and, 327, 327f
meeting needs and, 329–330
MyPlate and, 326, 326f
neural tube defects and, 327–328
pregnancy and, 327–328, 546–548, 546f
recommended intake and, 329
reducing birth defects and, 547
spina bifida and, 328, 328f
structure of, 326, 326f
supplements and, 313t, 329
tobacco smokers and, 327
toxicity and, 331
vitamin B_{12} and, 333–334
Folic acid. *See* Folate
Food additives, 661, 665–668, 666t
direct food additives, 665
flavor and color and, 665–666
generally recognized as safe (GRAS) substances, 668
indirect food additives, 664
nitrosamines and, 668
nutrient content and texture and, 665
nutritional quality and, 665
prior-sanctioned substances and, 668
regulation of, 666–667
safety of, 667
spoilage prevention and, 665
standards of identity and, 666–667
texture and, 665
used before 1958, 668
Food allergies
diagnosing, 590–591
digestive system and, 97–98
elimination diets and, 590–591
food challenge and, 590–591
genetically modified foods and, 680
immune system and, 89
infants and children and, 590–591
preventing and managing, 591
undigested protein and, 209–210
Food and Agriculture Organization (FAO), 697
Food and Drug Administration (FDA), 682–683
Foodborne Diseases Surveillance Network (FoodNet), 640
Food-borne illness, 636–637, *See also* Food Safety
preventing, 638–642, 650–653
types of, 642–650
Food-borne infection, 642
Food-borne intoxication, 642
Food chain contaminants, 654, 655f
Food challenge, 590–591
Food choices, 4–6
availability and, 4–5, 4f
cost of convenience and, 6, 7f
food processing and, 6
health status and, 5
peer pressure and, 5, 5f
personal preferences and, 5–6
psychological and emotional factors and, 5
social and cultural considerations and, 5, 5f
Food Code, 639
Food cravings and aversions, pregnancy and, 551
Food deserts, 704, 704f
Food diary, 63–64
Food disappearance surveys, 67, 67f
Food Distribution Program on Indian Reservations, 632t, 706t
Food environment, 4
Food fortification, 700–702
Food frequency questionnaire, 63f, 64
Food groups, diets and, 275
Food guide timeline, 34f–35f
Food insecurity
aging and, 617, 629–631
poverty and, 690
United States and, 703–707, 703f
Food intake record, 63–64, 63f
Food irradiation, 663–664, 663f
Food jags, 587
Food labels, 52–55
calcium and, 432
calorie consumption and, 252
carbohydrate recommendations and, 142–144, 143f
cholesterol and, 186, 186f
choosing wisely and, 54
daily values and, 52
fat content and, 184–186, 185f
fresh grocery products and, 58–59
genetically modified foods and, 682–683, 683f
ingredient list and, 55, 55f
iron and, 453, 453f
nutrition facts and, 52, 53f
proteins and, 222, 231
requirements regarding, 58–59
restaurant and vending machine food and, 59, 59f
safety and, 640
serving size and, 52
sodium and, 409–410, 410t
vitamins and, 310, 310f
Food packaging, 664–665
Food pathogens, 642–650, 643t
bacteria and, 644–646
food-borne infection and, 642
food-borne intoxication and, 642
molds, 648–649, 648f
parasites, 649, 649f
prions, 649–650, 650f
viruses, 646–648, 647f
Food processing, definition of, 6, biotechnology and, 678
Food quality, biotechnology and, 678
Food recovery, 707
Food safety
absorption and, 637
accidental contaminants, 661
antibiotics and hormones and, 657–658
aseptic processing and, 661, 661f
away from home, 653
bioaccumulation and, 654
contaminants and, 654, 655f
contamination sources, 636, 637f
cross-contamination and, 636
customer contamination and, 641–642
food additives and, 665–668, 666t
food-borne illness, 636
food handling and, 651–652
food pathogens, 642–650, 643t
food storage and, 651, 652t
government's role and, 638–640, 638t
hazard analysis critical control point, 639–640, 639t, 641t
industrial waste and, 658–659
irradiation and, 663–664, 663f
life cycle and, 637
manufacturers and retailers and, 640–642
microbial growth factors and, 660–661, 661t
packaging and, 664–665
pasteurization and, 640, 662
pathogens and, 636
pesticides and, 654–657
potential problem identification, 639–640
pregnancy and, 557, 557t, 637
proper labeling and, 640
risk reduction and, 650–653
safe cooking and, 652, 653t
sneeze guards and, 642, 652f
technology for, 660–668
temperature and bacterial growth, 651, 651f, 661–663
threshold effect and, 637
toxins and, 636
tracking food-borne illness, 640
wise food choice and, 659–660
Food Safety Modernization Act, 639
Food security, 697–698
Food self-sufficiency, 698
Food shortages, 689–693
Food stabilizers, 666t
Food storage, 651, 652t
Food texture, additives and, 665
Fortification
definition of, 304
malnutrition and, 700
Fortified food, 8
Free radicals, 336
Fresh grocery products, food labeling and, 5859
Fried foods, fat consumption and, 184
Fructose, 114–115, 115f
Fruit recommendations, 140
Fruits, phytochemical-rich diet and, 381, 382f
Functional fiber, 118
Functional foods, benefits of, 377, 377t
Futile cycling, 267

G

Galactose, 115, 115f
Gallbladder abnormalities, 92
Gallbladder disease, obesity and, 242–243
Gallstones, 95t, 243
Garlic, 487–489, 487f, 488t
Gastric banding, 280, 280f
Gastric bypass, 280–281, 280f
Gastric inhibitory peptide, 78t
Gastric juice, 81
Gastric pits, 81
Gastric sleeve surgery, 280, 280f
Gastrin, 78t, 82
Gastritis, atrophic, 99
Gastroenteritis, 646, 647f
Gastroesophageal reflux disease (GERD), 73, 91–92, 92f, 95t, 106
Gastrointestinal tract
  aging and, 614
  antibodies and, 89
  antigens and, 89
  common digestive complaints and, 90–96
  crowding in pregnancy, 541, 542f
  disorders, 65
  fiber affects on, 121, 121f
  food allergies and, 89
  gluten-related disorders and, 89–91
  gut wall structure and, 77
  health and, 87–97
  immune function and, 88–90
  intestinal microbiota and, 87–88
  mucosa and, 77
  organs of, 76, 76f
  transit time and, 76
Gender
  basal metabolism and, 254
  osteoporosis and, 422
  visceral fat accumulation and, 249, 249f
  water intake and, 394
Gene expression
  glucagon and, 211
  nutrient levels and, 213
  regulation of, 211–213
  thyroid hormones and, 466, 466f
  vitamin A and, 350–351, 350f
  zinc and, 213, 456, 457f
Generally recognized as safe (GRAS) substances, 668
Genes
  diet and genetic makeup, 13–14, 14f
  genetic modification, 675–676
  nutritional genomics, 14
  protein synthesis and, 211
Genetic engineering. *See* Biotechnology
Genetically modified foods, 679–683
  antibiotic resistance and, 680–681
  antigens and toxins and, 680
  biodiversity and, 681
  consumer safety and, 680–681
  environmental concerns and, 681–682
  Environmental Protection Agency (EPA) and, 683
  field testing and, 682, 682f
  Food and Drug Administration (FDA) and, 682–683
  labeling of, 682–683, 683f
  nutrient content changes and, 680
  regulation of, 682–683
  safety determination and, 682
  superbugs and superweeds and, 681–682
  U.S. Department of Agriculture (USDA) and, 683
  worldwide growth of, 679, 680f
Genetically modified organisms (GMOs), 671
Genetics
  aging and, 611–612, 612f
  body fat location and, 249
  body size and shape and, 262–263, 263f
  bone density and, 422
  eating disorders and, 286
  hypertension and, 402
Germ (grain), 111
Germanium, 475
Gestation, 538
Gestational diabetes, 129, 543
Gestational hypertension, 542
Ghrelin, 78t, 264
Giardia lamblia, 643t, 649, 649f
Gingko biloba, 486–487, 487f, 488t
Ginseng, 487, 487f, 488t
Globesity, 240
Glomerulus, 106
Glucagon, 125
Glucogenic amino acids, 126
Gluconeogenesis, 125, 126–127
Glucosamine supplements, 484, 484f
Glucose
  acetyl-CoA formation and, 125
  blood glucose levels and, 123
  cellular respiration and, 125, 126f
  citric acid cycle and, 125
  delivery to body cells, 123–125
  electron transport chain and, 125
  energy production and, 125
  fasting and, 258
  glucagon secretion and, 125
  gluconeogenesis and, 125
  glycemic index and, 123–124
  glycemic load and, 124
  glycemic response, 123
  glycolysis and, 125
  insulin and, 124
  molecules, 104
  photosynthesis and, 114, 115f
  proteins and, 126–127, 127f
  regulation of, 124, 124f
  role of, 114
  storage of, 257, 257t
Glucosinolates, 378t
Glutamine, 524t
Glutathione peroxidase, 462, 462f
Gluten, 89–91, 223
Gluten-related disorders, 89–91, 223
Glycemic index, 123–124
Glycemic load, 124
Glycemic response, 123
Glycerol, 524t
Glycogen
  carbohydrate consumption and, 520, 520f
  exercise and, 507
  fasting and, 258
  maximizing glycogen stores, 520
  role of, 116–117, 117f
  storage of, 257, 257t
  supercompensation, 117, 520
  synthesis of, 104
Glycolysis, 103, 125
Goiter, 466–468, 467f, 694, 695f
Goitrogens, 467
Golden rice, 352, 678, 678f
Gout, 244
Government role, food safety and, 638–640, 638t
Granola, 54f
Green tea, 278
Ground beef contamination, 645, 645f
Growth charts, infant, 567, 567f
Growth hormone
  aging and, 616
  muscle building and, 525–526
Growth monitoring, children and, 581–582, 581f
Growth spurts, adolescents and, 597
Growth stunting, undernutrition and, 687, 687f
Gums, 187, 187f
Gut homeostasis, 87, 88f
Gut wall structure, 77

H

Hazard analysis critical control point (HACCP), 639–640, 639t, 641t
Head Start, 706t
Health and nutrition, 12–18
  balance and, 17–18, 18f
  diet choice and, 14–18
  genetic makeup and, 13–14
  malnutrition and, 12
  meals away from home and, 16
  moderation and, 18
  nutrient density and, 14–16, 17f
  overnutrition and, 13, 13f
  undernutrition and, 12–13, 13f
  variety and, 16–17
Healthy Eating Index (HEI), 64
Healthy Eating Plate, 61, 62f
Healthy People 2020, 60, 706t
Heart. *See* Cardiovascular system
Heartburn
  esophagus and, 80
  gastroesophageal reflux diesease and, 91–92, 92f
  nutritional consequences and, 95t
  pregnancy and, 541
Heart disease
  alcohol consumption and, 177, 200
  B vitamins and, 177
  carbohydrates and, 135, 135f
  children and, 580
  coconut oil and, 176
  diabetes mellitus and, 130
  dietary cholesterol and, 173, 173f
  dietary patterns and, 173–175, 174f–175f
  epidemiologic studies and, 22
  iron intake and, 452
  monounsaturated fats and, 176–177
  nutritional assessment and, 65
  plant foods and, 177
  polyunsaturated fats and, 175–176
  protein excess and, 223
  risk factors and, 172–177, 172t
  saturated fats and, 174
  trans fats and, 174–175
Heat cramps, 516
Heat exhaustion, 516
Heat-related illness, 515–517, 516f
Heat stroke, 516
Heimlich maneuver, 80
Helicobacter pylori (H. pylori), 92, 94
Heme iron, 444–445, 446f

Hemochromatosis, 451
Hemoglobin
protein and, 207, 207f, 216f
iron and, 444–445, 446f, 447f, 448, 449f, 474t
vitamin B_6 and, 322
Hemolytic anemia, 365
Hemolytic uremic syndrome, 644
Hemorrhoids, 135, 541
Hemosiderin, 448
Hepatic portal circulation, 99, 101, 101f
Hepatic portal vein, 101, 101f
Hepatitis, alcoholic, 197
Hepatitis A, 643t, 647–648
Hepcidin, 447–448
Herbal laxatives, 278
Herbal supplements, 486–489
availability and expense, 486
benefits and side effects, 486, 488t
botanicals and, 486
caution regarding, 373
considerations when choosing, 486, 486t
echinacea, 487f, 489
garlic, 487–489, 487f
ginkgo biloba, 486–487, 487f
ginseng, 487, 487f
kava, 487f, 489
safety and, 627
saw palmetto, 487f, 489
St. John's wort, 487, 487f
Herbicide resistance, biotechnology and, 677
Herbicide-resistant weeds, 681–682
Herbs, pregnancy and, 556–557
Hesperidin, 485
Heterocyclic amines, 661
Hiatal hernia, 92, 95t
High-density lipoproteins (HDLs), 165
High-fiber diets, 118, 134
High-fructose corn syrup, 112–113
High-protein diets, 277
High-quality protein, 228–229
HMB (beta-hydroxy-beta-methylbutyrate), 524t, 526
Homeless Children Nutrition Program, 706t
Homelessness, 704–705
Homeostasis
definition of, 12
gut, 87
cell membrane and, 101
Homocysteine, cardiovascular disease and, 177, 324, 324f
Honey, infants intake and, 586
Hookworm infection, 694, 694f
Hormone-sensitive lipase, 169
Hormones
digestive hormones, 78, 78t
food safety and, 657–658
lactation and, 560, 560f
levels of and aging, 615–616
protein hormones, 216–217
secretion of, 75
supplements, 483–484
Human intervention studies, 21
Humectants, 666t
Hunger, 686. *See* Undernutrition and hunger
Hybridization, 675, 675f
Hydration, protein excess and, 220
Hydrochloric acid, 81
Hydrogenation, 157
Hydrolysis reactions, 116, 116f
Hydroxyapatite, 418
Hyperactive behavior, children and, 591–592
Hypercarotenemia, 356–357, 356f
Hypertension, 401–403. *See also* Blood pressure
causes of, 402
children and, 580
diabetes and, 402
diet and, 402–403
life cycle and, 402
obesity and, 402
pregnancy and, 542–543
race and, 402
risk factors and, 402
salt intake and, 397, 403
Hypertrophy, 493
Hypoglycemia, 132–133
Hyponatremia, 393, 517, 517f
Hypothermia, 515
Hypotheses, 19, 19f

I

Illicit drug use, pregnancy and, 558–559
Immature infant digestive tract, 97–98
Immune function
aging and, 616
gastrointestinal tract and, 88–90
vitamin A and, 354
vitamin B_6 and, 325
Immunizations, 217
Implantation process, pregnancy and, 536
Incomplete dietary proteins, 229
Indirect calorimetry, 259, 259f
Indirect food additives, 664
Indispensable amino acids, 206, 206f
Indoles, 378, 378t, 379
Industrial wastes, contamination from, 658–660
Infant formula. *See* Bottle-feeding
Infants. *See also* Bottle-feeding; Breast-feeding; Newborn feeding
abnormal growth and, 568
anemia and, 583
bone health and, 583
botulism and, 646
calcium and, 428, 431, 583
carbohydrate intake and, 564
carbohydrate recommendations and, 582
dehydration and, 393, 565
DHA-fortified formulas and, 565
energy and protein needs and, 563–564, 563f, 582, 582f
failure to thrive and, 568
fat recommendations and, 564
first foods introduced and, 585–586, 585f
fluoride requirements and, 566
food allergies and intolerances and, 590–591
growth and nutritional status, 566–568
growth charts and, 567, 567f
honey intake and, 586
increasing food variety and, 586
introducing solid foods to, 585
iron needs and, 566, 583
macronutrient needs and, 563–564, 563f
meeting nutrient needs and, 583–589
micronutrient needs and, 566, 582–583
mortality rate, undernutrition and, 687
nutritional needs and, 562–568, 563t, 582–583
protein absorption and, 210
typical meal patterns for, 584t
vitamin B_{12} needs and, 566
vitamin D needs and, 566, 566f, 583
vitamin E needs and, 365
vitamin K needs and, 566
water and electrolytes and, 564–565, 582
Infectious gastroenteritis, 646, 647f
Inflammation
alcohol consumption and, 200
atherosclerosis and, 167, 167f, 171f
Inflammatory bowel disease, 87
Ingredient list, food labels and, 55, 55f
Inorganic molecules, 9
Inositol, 378t
Inositol supplements, 485
Insect resistance, biotechnology and, 677, 677f
Insect-resistant crops, 681
Insensible losses, water and, 391
Insoluble fiber, 118, 118f
Instant energy, 503, 503f
Insulin
aging and, 616
alcohol consumption and, 200
blood glucose and, 124
body fat regulation and, 264
chromium and, 469, 469f
diabetes treatment and, 132–133
eating disorders and, 299
resistance to, 128
Integrated pest management, 656
Integumentary system, 75t
International trade, food availability and, 699
Interstitial fluids, 388
Intestinal gas, fiber and, 121–122
Intestinal juice, 84
Intestinal microbiota, 86, 87–88
functions of, 87, 88f
healthy *vs.* unhealthy, 87
maintaining healthy, 87–88
Intestinal microflora. *See* intestinal microbiota
Intestinal parasites, 694, 694f
Intoxication, water, 393
Intracellular fluids, 388
Intrinsic factor, 332, 332f
Iodine, 464–468, 474t
absorption of, 465
cretinism and, 467
deficiency and, 466–467
in the diet, 465
functions in body, 465–466
gene expression and, 466, 466f
goiter and, 466–468, 467f
goitrogens and, 467
iodized salt and, 467–468
life cycle and, 468
pregnancy and, 467–468
recommended intake and, 468
thyroid hormones and, 466–467, 466f
thyroid-stimulating hormone and, 466, 467f
toxicity and, 468
undernutrition and hunger and, 694–695
Iodized salt, 467–468, 701–702, 702f
Ions, 386
iProfile diet analysis, 64, 65f
Iron, 444–454, 454t, 474t
absorption, 337
adolescents and, 599–600
anemia and, 448–450, 514
calcium and, 446
cancer risk and, 452–453

Iron (*continued*)
deficiency and, 448–450, 449f, 450f
diabetes and, 452
in the diet, 444–445
in digestive tract, 445–446
ferritin and, 446
food labels and, 453, 453f
functions in body, 448
heart disease and, 452
heme iron, 444–445, 446f
hemochromatosis and, 451
hemosiderin and, 448
hepcidin and, 447–448
homeostasis and, 337f, 446–448
infants and children and, 566, 583
iron overload, 450
life cycle and, 449–450
losses and recycling, 448
myoglobin and, 445
MyPlate and, 444–445, 445f
nonheme iron, 445
older adults and, 624
pregnancy and, 449–450, 548
recommended intake and, 450
storage of, 448
supplements and, 451, 451f, 453
toxicity and, 450–453
transferrin and, 446
undernutrition and hunger and, 693–694
vegetarian diets and, 235
vitamin C and, 445–446
Irradiation, food protection and, 663–664, 663f
Irritable bowel syndrome, 87, 95t
Isomers, 363–364
Isothiocyanates, 378, 378t
Isotopes, 259

J

Joint disorders, excess body weight and, 243–244

K

Kava, 487f, 488t, 489
Keratinization, 354
Keratomalacia, 354
Keshan disease, 462, 463f, 695
Ketoacidosis, 130
Ketogenic amino acids, 126
Ketone bodies, 127
Ketones
appetite suppression and, 134
as energy source, 169
fasting and, 258
formation of, 127
Ketosis, 127
Kidneys
aging and, 614
kidney stones, 220–223, 433
metabolic waste elimination and, 106
nutritional assessment and, 65
protein excess and, 220
Kilocalorie (kcalorie, kcal), definition of, 9
Kilojoule (kjoule, kJ), definition of, 9
Kinky hair disease, 458
Kwashiorkor, 218–220, 219f, 693, 693f

L

Laboratory measurements, nutritional assessment and, 66
Laboratory studies, 21
Lactalbumin, 569
Lactase, 119
Lactation
colostrum and, 559
definition of, 536
energy needs and, 560–561, 561f
hormones and, 560, 560f
macronutrient needs and, 560–561, 561f
maternal nutrient needs and, 560–562
micronutrient needs and, 561, 562f
milk production and letdown, 559–560, 559f
oxytocin and, 560
prolactin and, 560
water needs and, 561
Lacteal, 83–84
Lactic acid, 503
Lactobacilli, 121
Lacto-ovo vegetarian diets, 232t, 233, 235
Lacto-vegetarian diets, 232t, 233, 235
Lactose, 115f, 116
Lactose intolerance, 120–121, 120f
Large for gestational age, 539, 539f
Large intestine, 86
Lauric acid, 174
LDL receptor, 163,163f, 164
Lead
children and, 592
lead poisoning, 659
physiological role and, 475
Lean body mass, 246
Lean meat, 184
Leavening agents, 666t
Lecithin, 9, 158, 158f
Legumes, 10, 111
Leptin, 264–266, 265f
Life expectancy, 609–610
Life span, 608–609
Lifestyle, aging and, 611–612, 612f
Lignin, 118
Limiting amino acids, 213, 213f
Limonene, 378t
Linoleic acid, 157, 166, 167
Lipases, 84
Lipids. *See also* Fat
adipose tissue and, 165, 165f
body process regulation and, 166–167
cardiovascular disease and, 170–177
cholesterol, 159, 160f, 165
choosing healthy fats and, 180–181, 183t
chylomicrons and, 162
dietary fat and cancer, 177–178
dietary fat and obesity, 178
in digestive tract, 160–161, 161f
eicosanoids and, 167
essential fatty acids and, 166–167, 166f
fat intake recommendations, 178–187, 179f
fat storage and retrieval, 167–169, 169f
fats in our food, 152–153, 152f
food labels and, 184–186, 185f
functions in body, 165–169
high-density lipoproteins and, 165
life cycle recommendations and, 179f
lipid bilayers, 158, 158f
lipoprotein lipase and, 162
lipoproteins and, 161, 162f
liver and, 162–163
low-density lipoproteins and, 162f, 163
micelles and, 160
MyPlate and, 181–184, 182f
phosphoglycerides, 158, 158f
phospholipids, 158
small intestine and, 162
sources of, 10, 10f
sterols, 159
structure and lubrication and, 165–166
transport and delivery, 161–165, 163f
triglycerides and energy, 167, 168f
triglycerides and fatty acids, 154–158
types of, 154–160
very-low-density lipoproteins and, 162–163, 162f
Lipofuscin, 611
Lipoic acid, 339
Lipoprotein lipase, 162
Lipoproteins, 161, 162f
Liposuction, 281
Listeria monocytogenes, 643t, 645
Lithium, 475
Liver
aging and, 614
alcohol affects and, 197
alcoholic hepatitis and, 197
cancer and, 648, 648f
cirrhosis and, 197, 198f
fatty liver, 197
lipid transport and, 162–163
nutrient delivery and, 100–101
Long-chain triglycerides (LCTs), 176
Longevity, 612
Long-term energy, 503f, 505
Lorcaserin (Belviq), 277
Low-birth weight, undernutrition and, 687
Low-carbohydrate diets, 276, 276f–277
Low-density lipoprotein (LDL) cholesterol, 173–177
Low-density lipoproteins (LDL), 162f, 163
Low-fat diets, 276, 276f
Low-fat products, 186–187, 187f
Low-intensity exercise, 506–507
Low-sodium diets, 410
Lubrication, water and, 386
Lumen, 76–77
Luo han guo extract, 146t
Lutein, 485
Lycopene, 378–379, 379f
Lymphatic system, nutrient delivery and, 101
Lymphocytes, 89
Lysine, 524t
Lysozyme, 79

M

Macrocytes, 327, 327f
Macrocytic anemia, 327, 327f
Macronutrient needs
choice (exchange) lists and, 61, 61f, 61t
dieting and, 276–277
infancy and, 563–564, 563f
lactation and, 560–561, 561f
older adults and, 621–622
pregnancy and, 543–544, 543f
Macrophages, atherosclerosis and, 170
Macular degeneration, 379, 613
Mad cow disease, 649–650
Magnesium, 436–438, 439t
adenosine triphosphate and, 437, 437f
deficiency and, 437–438

in the diet, 436
digestive tract and, 436
as enzyme cofactor, 437
functions in body, 437
kidney and, 437
life cycle and, 438
MyPlate and, 436, 437f
recommended intake and, 438
sodium-potassium pump and, 437
supplements and, 438
toxicity and, 438
Major minerals, 414, 414f
Making weight, athletes and, 510, 510f
Male eating disorders, 206f, 295–296
Malignancy, cancer cells and, 136, 136f
Malnutrition. *See also* Undernutrition and hunger
alcohol abuse and, 197
averting, 631
body composition changes and, 614–615
causes and consequences of, 612–613, 613f
consequences throughout life, 693, 694t
economic, social, psychological factors and, 620–621
eliminating world hunger, 697–703
federal programs and, 706t, 707–708
food fortification and, 700–702
gastrointestinal function and, 614
hormone levels and, 615–616
hunger and undernutrition causes, 689–696
hunger at home, 703–708
immune function and, 616
maternal, 553–554
medical conditions and, 617–620
nutrition transition and, 688, 689f
over-the-counter medications and, 618–620, 619t
overnutrition and, 688, 688f
poverty and, 687, 687f, 690–691, 690f
prescription medications and, 618–620, 619t
protein-energy malnutrition, 693
sensory decline and, 613
severe acute malnutrition, 693
supplementation and, 702
two faces of, 686–689
undernutrition impact, 686–688, 686f
warning signs of, 630t
Maltose, 115, 115f
Manganese, 460–461, 474t
deficiency and, 460–461
food sources of, 460, 460f
functions in body, 460
recommended intake, 461
toxicity and, 460–461
Marasmus, 218–220, 219f, 693, 693f
Marijuana, pregnancy and, 558
Mass media, body ideal and, 287, 287f
Material transport, water and, 386
Maternal health status, pregnancy and, 554–555
Maternal malnutrition, pregnancy and, 553–554
Maximum heart rate, aerobic activity and, 498
Meat, fat content and, 184
Medical history, nutritional assessment and, 65, 65f
Medical limitations, older adults and, 630–631
Mediterranean Diet, 173, 175f, 178, 406
Medium-chain triglycerides (MCTs)
coconut oil and, 176
as ergogenic aid, 524t
supplements, 530
Megaloblastic anemia, 695
Melanocortin-4 receptor gene, 286
Melatonin, aging and, 616
Melatonin supplements, 483, 483f
Menaquinones, 367
Menarche, 597
Menkes disease, 458
Menopause
calcium intake and, 430
estrogen and, 615–616
osteoporosis and, 422
Menu calorie labeling, 59, 59f
Mercury, pregnancy and, 556
Mercury poisoning, 659
Messenger RNA (mRNA), 211
Metabolic pathway, 103
Metabolic reactions, water and, 387
Metabolic syndrome, 129, 242
Metabolic waste elimination, 105–106, 105f
Metabolism, alcohol, 193–194, 194f
Metallothionein, 455
Micelles, 160
Microbial growth factors, 660–661, 661t
Microbiota. *See* Intestinal microbiota
Microflora. *See* Intestinal microbiota
Micronutrients. *See also* Vitamins and minerals
adolescents and, 598–600
classificaiton of, 9
infants and children and, 566, 582–583
lactation and, 561, 562f
older adults and, 622–624, 623f
pregnancy and, 545, 545f
roles of, 11
sources of, 11
Microsomal ethanol-oxidizing system, 194, 194f
Microvilli, 83
Milk. *See also* Bottle-feeding; Breast-feeding; Vitamin D
calcium and, 431, 431f
consumption trends and, 67, 67f
milk-alkali syndrome, 433
production and letdown, 559–560, 559f
riboflavin and, 314, 314f, 315
Millennium Development Goals, 698f
Minerals. *See also* Trace minerals, Major minerals
absorption and, 416–417, 417f
athlete requirements and, 512–515
bioavailability and, 416–417
bone structure and remodeling and, 418–420, 419f
calcium, 427–434
children and, 587–588
cofactors and, 417, 418f
deficiencies and, 416
dietary supplements and, 416
ergogenic aids and, 523–525
food processing and, 415–416
function of, 11
magnesium, 436–438
major minerals and, 414
MyPlate and, 414, 415f
natural food sources of, 415
older adults and, 622–625, 623f
osteoporosis and, 420–427
in our diet, 414–416
periodic table and, 414, 414f
phosphorus, 434–436
pregnancy and, 545, 545f
recommended intakes and, 417
sulfur, 438
toxicity and, 416
trace minerals and, 414
transport and, 417
understanding needs and, 416–418
Miscarriage, 537
Misleading claims, nutrition information and, 27–28
Mitochondria, 101
Mobility, aging and, 617
Modern agriculture, natural resources and, 691–693
Modified-atmosphere packaging (MAP), 664
Molds, 648–649, 648f
Molecule formation, atoms and, 74, 74f
Molybdenum, 473–475, 474t
deficiency, 473–475
in the diet, 473
recommended intake, 475
toxicity, 475
Monoacylglycerol, 154
Monoglyceride, 154
Monosaccharides, 114–115, 115f
Monosodium glutamate (MSG), 224
Monounsaturated fatty acids
food labeling and, 186
heart disease and, 176–177
oleic acid, 156–157
Morning sickness, 96, 541
Mouth, digestion and absorption and, 79
MSG symptom complex, 224
Mucosa, 77
Mucus, 77
Muscle building
anabolic steroids and, 526, 526f
growth hormone and, 525–526
HMB and, 526
protein supplements and, 525
steroid precursors and, 526
supplements and, 525–526, 526f
Muscle contraction, electrolytes and, 397–398
Muscle dysmorphia, 295t, 296
Muscle strength and endurance, 483f, 493–494
Muscle-strengthening exercises, 499
Muscular system, 75t
Mutations, cancer cells and, 136
Myoglobin, 445
MyPlate, 45–51
adolescents and, 600f, 601f
blood pressure and, 406–407, 406f
calcium and, 427–428, 427f
calorie needs and, 48, 48t
carbohydrates and, 139, 140f
children and, 586–587, 587f
choline and, 341, 341f
daily food plan and, 46–51
dietary guidance and, 35–37, 35f
empty calories and, 49–51, 51f
equivalencies and, 46, 47t
estimated energy needs and, 48t
folate (folic acid) and, 326, 326f
food groups and energy levels and, 48t
iron and, 444–445, 445f
magnesium and, 436, 437f
menaquinones and, 367
minerals and, 414, 415f

MyPlate (*continued*)
moderation and, 45
niacin and, 316–318, 316f
nutrient density and, 45
oils and fats and, 48, 49f
older adults and, 625–626, 626f
pantothenic acid and, 320, 321f
phosphorous and, 434, 434f
phylloquinone and, 366
pregnancy and, 548–549, 549f
proportionality and, 45
proteins and, 230, 231f
recommendations and, 45, 46f
selenium and, 461–462, 461f
thiamin content and, 311, 311f
understanding, 45
variety and, 45
vegetarian diets and, 235, 236f
Vitamin A and, 347, 347f
vitamin B_6, 321–322, 322f
vitamin B_{12} and, 331–332, 331f
vitamin C and, 335–336, 335f
vitamin D and, 357, 357f
vitamin K and, 366–367, 367f
vitamins and, 304, 305f
water intake and, 390, 390f
zinc and, 454, 455f

N

National Health and Nutrition Examination Survey (NHANES), 67–69
National Molecular Subtyping Network for Foodborne Disease Surveillance (PulseNet), 640
National School Lunch Program, 706t
Natural toxins, 656
Neotame, 146t
Nephrons, 106
Nerve conduction, electrolytes and, 397–398, 398f
Nerve functions, vitamin B_6 and, 322, 323f
Nervous system functions, 75t
Net protein utilization, 229, 229f
Neural tube, 327–328, 328f, 546–547, 546f
Neural tube defects, folate deficiency and, 327–328
New molecule synthesis, 104–105
Newborns. *See also* Infants
bottle-feeding, 571–573
breast-feeding, 568–571
feeding of, 568–573
vitamin K deficiency and, 369
Niacin, 315–319
beans and tortillas and, 318, 318f
corn-based diet and, 318, 318f
deficiency and, 318
in the diet, 316–318
flushing and, 319
functions in body, 318
heart disease and, 177
high-protein foods and, 318
life cycle and, 318
MyPlate and, 316–318, 316f
niacin equivalents and, 318
nicotinamide adenine dinucleotide and, 318
nicotinamide adenine dinucleotide phosphate and, 318
pellagra and, 315–318, 319f
pregnancy and, 318
recommended intake and, 318
supplements and, 313t, 319
toxicity and, 319
tryptophan and, 316–318, 316f
Niacin equivalents (NEs), 318
Nickel, 475
Nicotinamide adenine dinucleotide (NAD), 194, 318
Nicotinamide adenine dinucleotide phosphate (NADP), 318
Nicotinic acid, heart disease and, 177
Night blindness, vitamin A deficiency and, 350, 354
Night-eating syndrome, 295t
Nitrogen balance, 225–226, 225f
Nitrosamines, 668
Non-celiac gluten sensitivity, 89–90
Nonessential amino acids, 206, 206f
Nonexercise activity thermogenesis (NEAT), 255, 267, 267f
Nonheme iron, 445
Nonnutritive sweeteners, 145–147, 146t
Norovirus, 643t, 646–647
Nursing bottle syndrome, 573, 573f
Nutraceuticals, 383
Nutrients, 8–12
body processes and, 12
body structure and, 12
calories in foods and, 9, 9f
defined, 4
dietary supplements and, 8
energy function of, 11
energy-yielding nutrients, 9–10
enriched grains and, 8
essential nutrients and, 8
fortified foods and, 8
function of, 11–1 2, 11f
inorganic molecules and, 9
macronutrients, 9
micronutrients, 9, 11
organic molecules and, 9
phytochemicals and, 9
six classes of, 9–11
water, 10–11
Nutrient content
additives and, 665, 666f
dietary supplement labels and, 56, 56t
genetically modified foods and, 680
Nutrient delivery, 99–102
body cells and, 101, 102f
cardiovascular system and, 99–101
lymphatic system and, 101
Nutrient density, MyPlate and, 45
Nutrient intake analysis, 64
Nutrient intake recommendations
Adequate intakes (AIs), 38–39
Estimated average requirements (EARs), 38
Recommended dietary allowances (RDAs), 38
Tolerable upper intake levels (ULs), 38f, 39
Nutrient metabolism, 102–105
adenosine triphosphate production and, 103–104, 103f
anabolism and catabolism, 102–103
coenzymes and, 103
metabolic pathway and, 103
new molecule synthesis and, 104–105
Nutrient supplements, 481–482. *See also* Dietary supplements
omega-3 fatty acids, 482, 482f
protein and amino acid supplements, 482
supplemental carbohydrate, 481–482
vitamins and minerals, 481
Nutrigenetics, 14, 14f
Nutrigenomics, 14, 14f
Nutrition, defined, 4
Nutrition education, providing, 708
Nutrition facts, food labels and, 52, 53f
Nutrition information
accurate scientific interpretation and, 29
anecdotal claims and, 27, 27f
common sense and, 26
evaluation of, 25–29, 26t
experimental controls and, 29
good science and, 27–29
information credibility and, 27
misleading claims and, 27–28
peer-review systems and, 29
source investigation and, 26–27
test of time and, 29
Nutrition Program for the Elderly, 632t, 706t
Nutrition Screening Initiative, 632t
Nutrition transition, poor countries and, 688, 689f
Nutritional assessment, 62–67
anthropometric measurements and, 64–65, 65f
diet history and, 64
dietary intake estimation and, 62–63
food diary or food intake records, 63–64, 63f
food disappearance surveys and, 67
food frequency questionnaire, 63f, 64
food supply monitoring, 67
iProfile diet analysis and, 64, 65f
laboratory measurements and, 66
medical history and, 65, 65f
nutrient intake analysis and, 64
nutritional deficiency and, 66–67, 66f
nutritional status monitoring, 67
physical exams and, 66
population studies, 67
twenty-four hour recall studies, 63, 63f
Nutritional deficiency, progression of, 66–67, 66f
Nutritional facts, calorie consumption and, 252
Nutritional genomics, 14
Nutritional quality
additives and, 665
biotechnology and, 678, 678f
Nutritional recommendations
development of, 34–37
early U.S. recommendations, 34–35
focus shift in, 35–36
food guide timeline, 34f–35f
government involvement and, 36
Nutritional science, 18–25
Nutritional status, 62

O

Oatmeal, 54f
Obesity. *See also* Body weight; Childhood obesity; Weight management
aging and, 614–615
alcohol abuse and, 197
cancer and, 243
cardiovascular disease and, 242
childhood stunting and, 687

diabetes and, 242
dietary fat and, 178
gallbladder disease and, 242–243
genes *vs.* environment, 262–263, 263f
hypertension and, 402
incidence rates and, 240, 240f
joint disorders and, 243–244
metabolic syndrome and, 242
obesity genes, 262, 262f
osteoporosis and, 424
psychological and social problems and, 244
sleep apnea and, 243
soda ban in schools and, 599
vitamin D supplementation and, 362
Obesogenic environment, 272
Observational studies, 20–21, 20f
Ocean resources, undernutrition and hunger and, 693, 693f
Older adults. *See also* Aging
antioxidants and, 624
B vitamins and, 623–624
building strength and, 629, 629f
calcium and, 429, 624
carbohydrate requirements and, 622
congregate meals and, 629–630, 630f
dehydration and, 515–516, 622
dependent living and, 620, 620f
depression and, 621
dietary supplements and, 626–628, 628f
easy meals and, 630, 630f
economic and social limitations and, 629–630
energy needs and, 621–622
fat intake and, 622
fiber requirements and, 622
food insecurity and, 629–631
good nutrition and, 624–625
healthy diet for, 625–628
healthy weight and, 625
herbal supplements and, 627
improving flexibility and, 6298
increasing endurance and, 628
iron and, 624
low-impact activities and, 628, 629f
low income and, 620
macronutrient needs and, 621–622
maintaining balance and, 629
medical limitations and, 630–631
medical nutritional products and, 630
medications and, 630–631
micronutrient needs and, 622–624, 623f
MyPlate recommendations and, 625–626, 626f
nutrition programs for, 631–632, 632t
osteoporosis and, 421–422, 421f
physical activity and, 628–629
physical limitations and, 630
protein needs and, 621–622
special diets and, 630
starting exercise program and, 628
underweight and, 244
vitamin D and, 361, 624
water requirements and, 622
weight management and, 269
zinc and, 624
Older Americans Act, 632, 632t
Older mother, 554–555
Olestra, 186–187, 187f
Oligosaccharides, 116
Omega-3 fatty acids
characteristics of, 157
eicosanoid and, 167
heart disease risk and, 175–176
MyPlate and, 182
structure of, 155f
supplements, 482, 482f
vegan diet and, 235
Omega-6 fatty acids
characteristics of, 157
eicosanoid and, 167
structure of, 155f
Oral contraceptive use, adolescents and, 603
Organ formation, cells and, 74, 74f
Organ systems, 74–75, 75t
Organelles, 101
Organic farming, 699
Organic food production, 656–658, 657f
Organic molecules, 9
Orlistat (Xenical), 277
Ornithine, 524t
Orthorexia nervosa, 295t
Osmosis
small intestine and, 84
water movement and, 388–389, 389f
Osteoarthritis
aging and, 617, 617f
excess body weight and, 243–244
Osteoblasts, 420
Osteoclasts, 420
Osteomalacia, 360–361
Osteopenia, 420
Osteoporosis, 420–427
alcohol use and, 422
body mass index and, 424
calcium intake and, 695
diet and, 424
drug therapy and, 426
female athlete triad and, 298, 298f
gender and, 422
genetics and, 422
health impacts of, 420, 420f
healthy bone compared, 420, 420f
menopause and, 422
obesity and, 424
older adults and, 421–422, 421f
physical activity and, 422–424
postmenopausal bone loss and, 422
prevention of, 424–426
risk factors and, 421, 421t
smoking and, 422
supplements and, 425–426
treatment of, 424–426
Outbreeding, 675
Over-the-counter medications, nutritional status and, 618–620, 619t
Overhydration, 393
Overload principle, 492
Overnutrition, 688, 688f
Overpopulation, undernutrition and hunger and, 691, 691f
Overtraining syndrome, 501
Overweight. *See* Body weight; Obesity
Oxidation, 104
Oxidation-reduction reactions, 104
Oxidative damage, 336, 464, 514
Oxidative stress, 336, 464–465
Oxidized LDL cholesterol, 170
Oxygen delivery to muscles, exercise and, 502–503, 502f
Oxylates, mineral absorption and, 416, 417f
Oxytocin, 560

P

PA (physical activity) value, 260
Pancreas
abnormalities and, 92
aging and, 614
lipases, 84
pancreatic amylases, 84, 119
pancreatic disease, 95t
pancreatic juice, 84
pancreatic proteases, 84
Pantothenic acid, 320–321
deficiency and, 320
in the diet, 320
functions in body, 320
MyPlate and, 320, 321f
recommended intake and, 320–321
toxicity and, 321
Parasites, 649, 649f
Parathyroid hormone (PTH), 358, 430
Parietal cells, vitamin B_{12} and, 332
Partially hydrogenated oils, 157
Pasteurization, 640, 662
Pathogens, 636
Peace Corps, 697
Peak bone mass, 420
Pectins, 187, 187f
Peer pressure, food choices and, 5, 5f
Peer-review systems, experiments and, 29
Pellagra, 315–318, 319f, 695
Pepsin, 81
Pepsinogen, 81
Peptic ulcers, 91, 92, 94
Peptide hormones, 217
Peptide YY, 264
Peridontal disease, aging and, 615
Peristalsis, 80, 80f, 86
Pernicious anemia, 331, 334
Pescetarian diets, 232t
Pesticides, 654–657
choosing food wisely and, 659–660
controlling exposure and, 655–656
genetic engineering and, 656
integrated pest management and, 656
natural toxins and, 656
organic methods and, 656–657, 657f
pesticide resistant insects, 681
pesticide tolerances, 655–656, 656f
risk reduction and, 656–657
Peyer's patches, 89f
pH
control agents, 666t
gastrointestinal tract and, 218
water and, 387, 388f
Phagocytes, 89f
Pharynx, 79–80, 79f
Phendimetrazine (Bontril), 277
Phentermine (Adipex), 277
Phenylalanine, 147
Phenylketonuria (PKU)
aspartame and, 147, 223–224, 224f
infant feeding and, 572
Phosphate, 434, 434f
Phosphocreatine, 503
Phosphoglycerides, 158, 158f

Phospholipids, 154, 158, 166
Phosphorus, 434–436, 439t
adenosine triphosphate and, 435, 435f
deficiency, 435–436
in the diet, 434
in digestive tract, 325
excessive, 436
functions in body, 435
life cycle and, 436
MyPlate and, 434, 434f
recommended intake and, 436
vitamin D and, 435
Photosynthesis, glucose production and, 114, 115f
Phylloquinone. *See* Vitamin K
Physical activity. *See also* Exercise
aerobic exercise and, 492–493, 493f
body composition and exercise, 494, 495f
body weight and, 241–242, 242f
bone and joint health and, 496
cancer risk and, 495–496
cardiopulmonary endurance and, 492–493, 493f
cardiovascular health and, 495
childhood obesity and, 596, 596f
determining level of, 259–260, 260f
diabetes prevention and management and, 495
endorphin production and, 496–497
energy expenditure and, 255–256, 256f, 267
energy needs and, 508–511, 509t
ergogenic aids and, 523–531, 524t
exercise and energy metabolism, 502–508
fitness and, 492–494
flexibility and, 494, 494f
fluid needs and, 515–519
health benefits of, 495–497, 495f
healthy weight loss and, 516
muscle strength and endurance and, 483f, 493–494
older adults and, 628–629, 628t
osteoporosis and, 422–424
overall well-being and, 496–497
overload principle and, 492
PA (physical activity) value, 260
pregnancy and, 540, 540t
unhealthy weight-loss practices and, 510
weight management and, 271, 496, 496f
Physical activity recommendations, 497–501
aerobic activity and, 498–499, 499f
children and, 500, 500f
convenient, enjoyable activities and, 500, 501t
creating active lifestyles and, 500–501
fitness programs and, 497, 497f
frequency, intensity, duration, 501
maximum heart rate and, 498
muscle-strengthening exercises, 499
overtraining syndrome and, 501
safety and, 500–501
stretching and, 499
Physical exam, nutritional assessment and, 66
Physical frailty, aging and, 614–615
Physical limitations, older adults and, 630
Phytates, mineral absorption and, 416, 417f
Phytic acid, 416
Phytochemicals
added *vs.* naturally occurring, 383
alliums, 379
antioxidants and, 377
carcinogens and, 378
carotenoids, 378–379
dietary choices and, 381–383
flavonoids, 379
indoles, 379
isothiocyanates, 379
nutraceuticals and, 383
in our food, 377–380, 378t
phytoestrogens, 380
plant proteins and, 382–383
supplements, 383
whole grains and, 382
Phytoestrogens, 377, 378t, 380
Phytosterols, 377, 378t
Pica, 295t, 296, 551, 551f
Pima Indians, 263, 263f
Placebos, experiments and, 29
Placenta, 537, 537f
Plant breeding, biotechnology and, 675, 676f
Plant foods, heart disease and, 177
Plant proteins, phytochemical-rich diet and, 382–383
Plant sources, proteins and, 204, 205f
Plasmids, 674, 674f
Plastic containers, bisphenol A and, 664, 664f
Polar nature, water and, 386, 386f
Polychlorinated biphenyls (PCBs), 659
Polycyclic aromatic hydrocarbons (PAHs), 661
Polyols, 147
Polypeptides, 81, 206
Polyphenols, 177
Polysaccharide
definition of, 114
digestion of, 119, 119f
types of, 116–118
Polyunsaturated fats
characteristics of, 157
food labeling and, 186
heart disease risk and, 175–176
Poor-quality diets, undernutrition and hunger and, 693–695
Population growth, controlling, 698
Population nutritional assessment, 67
Portion sizes, body weight and, 241, 241f
Postmenopausal bone loss, 422
Potassium, 396–400, 400t
deficiency and, 399–400
fluid balance and, 397, 397f
function in body, 397–398
homeostasis and, 399
muscle contraction and, 397–398
nerve conduction and, 397–398, 398f
in our food, 396–397, 396f
recommended intakes and, 403–406
toxicity and, 400
Poverty
cycle of, 705, 705f
disease and disability and, 687t, 690
education deficit and, 690–691
eliminating, 697–698
food insecurity and, 690
malnutrition and, 687, 687f
older adults and, 620
undernutrition and hunger and, 690–691, 690f
United States and, 703–704, 704f
Prebiotics, 87–88
Prediabetes or impaired glucose tolerance, 128f, 129
Preeclampsia, pregnancy and, 542–543
Pregnancy. *See also* Lactation
alcohol consumption and, 200, 557
biotin and, 320
caffeine and herbs and, 556–557
calcium and, 428, 431, 545–546
carbohydrate recommendations and, 544
cesarean section and, 539
changes in mother and, 538–549
chromium and, 470
cigarette smoke and, 558
complications of, 541–543
constipation and, 541
copper intake and, 460
critical development periods and, 556, 556f
dietary supplements and, 549–550, 551f
discomforts and, 96–97, 540–541
Down syndrome and, 555, 555f
eating disorders and, 296
eclampsia and, 542–543
edema and, 541, 541f
electrolytes and, 405–406, 545
energy needs during, 543–544, 543f
environmental toxins and, 556
factors increasing risks, 552–559, 552t
fat recommendations and, 544
fetal alcohol syndrome and, 557, 558f
fish consumption and, 659, 659f
folate (folic acid) and, 327–328, 546–548, 546f
food-borne illness and, 637
food cravings and aversions and, 551
food safety and, 557, 557t
gastrointestinal tract crowding and, 541, 542f
gestational diabetes mellitus and, 543
gestational hypertension and, 542
heartburn and, 541
hemorrhoids and, 541
high blood pressure and, 542–543
hypertensive disorders of, 542–543
iodine and, 467–468, 694
iron and, 449–450, 548, 694
legal or illicit drug use and, 558–559
Listeria infections and, 645
macronutrient needs during, 543–544, 543f
magnesium and, 438
malnutrition and, 553–554
maternal health status and, 554–555
maternal nutritional status and, 553–554
mercury in fish and, 556
micronutrient needs and, 545, 545f
mineral needs and, 545, 545f
morning sickness and, 541
MyPlate and, 548–549, 549f
neural tube formation and, 546, 546f
niacin and, 318
nutritional needs during, 543–551
older mother and, 554–555
phosphorus intake and, 436
physical activity during, 540, 540t
physiology of, 536–543
pica and, 551, 551f
preeclampsia and, 542–543
prenatal care and, 541–542, 543f
prenatal growth and development, 536–538, 536f
protein recommendations and, 544
reproductive history and, 554
riboflavin and, 315

socioeconomic factors and, 555
teenage pregnancy and, 554, 554f
teratogens and, 555–556, 556f
thiamin intake and, 313
toxic substances and, 555–559
trimesters and, 539
undernutrition and, 686–687
underweight and, 244
vitamin B_{12} and, 334, 548
vitamin C and, 338, 546
vitamin D and, 361, 546
vitamin E and, 366
vitamin needs and, 545, 545f
water needs and, 545
weight gain during, 538f, 539–540, 539f, 539t
weight management and, 269
zinc and, 457, 548
Premature infants, 538, 538f
Premenstrual syndrome (PMS), 325
Prenatal care, 541–542, 543f
Prenatal growth and development, 536–538, 536f
amniotic sac and, 537, 537f
embryo and, 537
fertilization and, 536
gestation and, 538
implantation and, 537
large-for-gestational age baby, 539, 539f
miscarriage and, 537
placenta and, 537, 537f
preterm or premature and, 538, 538f
small for gestational age and, 538
spontaneous abortion and, 537
very-low-birth weight infants, 538
zygote and, 536
Prenatal supplements, 549–550, 551f
Prepackaged meals and formulas, 275
Prescription medications, nutritional status and, 618–620, 619t
Preservatives, 665, 665t
Preterm infants, 538, 538f
Prions, 649–650, 650f
Prior-sanctioned substances, 668
Pro-oxidants, 336
Probiotics, 88
Programmed cell death, 611
Prolactin, lactation and, 560
Proteases, pancreatic, 84
Protein. *See also* Amino acids
acid-base balance and, 218
amino acid absorption and, 208–209, 209f
amino acid functions and, 210–215
amino acid structure and, 205–206, 206f
anaphylaxis and, 209
antibodies and, 217
athlete requirements and, 511–512, 511f
blood glucose and, 126–127, 127f
body processes and, 215–218
body structure and, 215
bone health and, 220
building muscle and, 525
cancer risk and, 223
complete dietary proteins, 228
contractile proteins, 217–218
deficiency, 218–220
denaturation and, 207–208, 208f
Dietary Guidelines for Americans and, 43
digestion and absorption and, 208, 208f
enzymes and protein hormones and, 215–217
excess, 220–223
exercise and, 505–506
fat synthesis and, 257, 258f
fluid balance and, 218
food allergies and, 209–210
food labels and, 222, 231
functions of, 10, 10f, 215–218, 216f
gene expression and, 211–213
heart disease and, 223
high-protein diets, 221
hydration and kidney function and, 220
incomplete dietary proteins, 229
infants and children and, 582, 582f
intake exceeding needs and, 215
intake recommendations, 224–231
kidney stones and, 220–223
kwashiorkor and, 218–220
low energy intake and, 215
marasmus and, 218–220
older adults and, 621–622
osteoporosis risk and, 424
in our diet, 204, 205f
pregnancy and, 544
protein-based fat replacers, 187, 187f
protein complementation, 230, 230f
protein deficiency, 218–220
protein-energy malnutrition and, 218–220, 219f
protein excess, 220–223
protein intolerances, 223–224
protein molecules, 205–208
protein quality, 228–230, 229f
protein-sparing modified fast, 275
protein structure, 206–208, 207f
protein turnover, 210–211
quality measurements, 229–230, 229f
resynthesis and, 210–211
severe acute malnutrition and, 218
storage of, 257, 257t
supplements, 228, 228f, 482
synthesis, 105, 211–213
three-dimensional shapes and, 206–207
transcription and, 211, 211f
translation and, 211, 211f
transport proteins, 217
vegetarian diets and, 232–236, 232t
vitamin B_6 and, 323
Protein digestibility-corrected amino acid score (PDCAAS), 229, 229f
Protein efficiency ratio (PER), 229, 229f
Protein-energy malnutrition, 218–220, 219f, 693
Protein recommendations, 224–231
acceptable macronutrient distribution ranges, 226
bioavailability and, 229
choice (exchange) lists and, 226, 226t
complementary proteins, 230, 230f
determining, 225–226
exercise and, 228
food labels and, 231
healthy diets and, 228–231
illness and injury and, 227
infants and, 564
life cycle and, 227, 227f
MyPlate and, 230, 231f
nitrogen balance and, 225–226, 225f
protein quality and, 228–230, 229f
recommended dietary allowances, 226
supplements and, 228, 228f, 482
Prothrombin, vitamin K and, 367
Provitamins, 308
Psychological factors, food choices and, 5
Psychological issues
anorexia nervosa and, 289
bulimia nervosa and, 291
excess body weight and, 244
Puberty, 597
Purging behavior
anorexia nervosa and, 289t, 290
bulimia nervosa and, 292
Pyloric sphincter, 82
Pyridoxal phosphate, 322
Pyridoxine, 322

Q

Qualified health claims, 57, 58f

R

Raw eggs, 319, 319f
Raw fish, 649, 649f
Recombinant bovine somatotropin (bST), 678–679
Recombinant DNA, 211, 674, 674f
Recommended dietary allowances (RDAs), 35, 38, 38f
Rectum, 86
Red Cross, 697
Reduced-fat foods, 186–187
Reduction reactions, 104
Reference daily intakes (RDIs), 52
Refined, definition of, 110, 110f
Refined carbohydrates, 110–111, 110f, 134
Rehydration, 393, 393f
Relative energy deficiency in sport (RED-S), 298, 511, 603
Remodeling, bone, 419–420, 419f
Renewable resources, undernutrition and hunger and, 691
Renin, 398, 399f
Reproductive history, pregnancy and, 554
Reproductive system, 75t
Reserve capacity, 611
Resistant starch, 118
Resorption, bone, 420
Respiratory system, 75t, 106
Restaurant menus, food labeling and, 59, 59f
Resting energy expenditure (REE), 254
Resting heart rate, 493
Resting metabolic rate (RMR), 254
Restricting type anorexia nervosa, 289t, 290
Restriction enzymes, 212, 674
Retin-A, 357
Retinoid supplements, 357t
Retinoids, 347–349, 348f
Retinol activity equivalents (RAEs), 355, 355f
Retinol-binding protein, 348
Rhodopsin, 349–350
Rhubarb, 377, 377f
Riboflavin
ariboflavinosis and, 315
deficiency and, 315
in the diet, 314
energy metabolism and, 315
flavin adenine dinucleotide and, 314–315
flavin mononucleotide and, 314–315
functions in body, 314–315
life cycle and, 315

Riboflavin (*continued*)
light exposure and, 314, 314f
MyPlate and, 314, 314f
recommended intake and, 315
supplements and, 315
toxicity and, 315
urine color and, 315
Rickets, 360, 360f, 584
Rubidium, 475
Rumination disorder, 295t
Rutin, 485

S

Saccharin, 146t
Saliva, 79
Salivary amylase, 79
Salmonella, 643t, 644, 644f
Salt appetite, 398
Salt sensitivity, 14
SAM-e supplements, 484
Saponins, 378t
Sarcopenia, 614–615, 615f
Satiety, 264
Saturated fatty acids, 155–156, 155f
Saw palmetto, 487f, 488t, 489
Scarsdale diet, 276
Scavenger receptors, 170
School Breakfast Program, 706t
School lunches, children and, 589, 589f
Science behind nutrition, 18–25
animal studies and, 23–24, 24f
balance studies and, 21, 24f
case-control studies and, 21
cellular studies and, 24, 25f
depletion-repletion studies and, 21
early science, 23
ethical concerns and, 24–25
human intervention studies and, 21
laboratory studies and, 21
observational studies and, 20–21, 20f
scientific method and, 19–20, 19f
Scientific method, 19–20, 19f
Scrapie, 649
Scurvy, 335, 337, 338f, 695
Secretin, 78t
Segmentation, small intestine and, 84, 84f
Selective breeding techniques, 675
Selective eating disorder, 295t
Selective estrogen receptor modulators (SERMs), 426
Selective permeability, 101
Selenium, 461–464, 474t
cancer and, 462–463
deficiency and, 462–463, 695
in the diet, 461–462
functions in body, 462
glutathione peroxidase and, 462, 462f
Keshan disease and, 462, 463f
life cycle and, 463
MyPlate and, 461–462, 461f
recommended intake and, 463
selenoproteins and, 462
supplements and, 463–464
toxicity and, 463
Selenoproteins, 462
Self-esteem, eating disorders and, 286
Semivegetarian diets, 232t
Senior Farmers' Market Program, 706t
Sensory decline, aging and, 613
Serving size, food labels and, 52, 252
Set point, 263–264
Severe acute malnutrition (SAM), 218, 693
Sexual development, underweight and, 244
Sexual maturation, adolescents and, 597
Shellfish farming, 670
Shigella, 643t
Short-chain fatty acids, 87
Short-term energy, 503–505, 503f
Short-term food aid, 697, 697f
Sickle cell disease, 207, 207f
Silicon, 475
Simple carbohydrates, 114–116
Single-bind study, experiments and, 29
Siraitia grosvenorii, 146t
Skeletal abnormalities, copper deficiency and, 460
Skeletal system, 75t
Skin, metabolic waste elimination and, 106
Skinfold thickness measurements, 247, 248f
Sleep apnea, 243
Small for gestational age infants, 538
Small intestine, 83–86
absorption mechanisms and, 86f
active transport and, 85, 86f
brush border and, 83
digestion and absorption and, 85f
facilitated diffusion and, 85
immune system cells in, 89, 89f
lacteal and, 83–84
lipid transport and, 162
microvilli and, 83
motility and secretions in, 84
nutrient absorption and, 84–86
osmosis and, 84
segmentation and, 84, 84f
simple diffusion and, 84
structure and function of, 83–84, 83f
villi and, 83
Smoking
adolescents and, 604
bone health and, 422
folate (folic acid) and, 327
pregnancy and, 558
vitamin C and, 338
Snacks, children and, 588, 588t, 589t
Sneeze guards, 642, 652f
Social changes, body weight and, 241
Social considerations, food choices and, 5
Social limitations, older adults and, 629–630
Social problems, excess body weight and, 244
Sociocultural factors, eating disorders and, 286–287
Socioeconomic factors, food choices and, 5
Soda ban, reducing obesity and, 599
Sodium, 396–400, 400t
blood pressure and, 398–399, 399f, 403, 406–407
deficiency and, 399–400
extracellular fluid volume and, 398
fluid balance and, 397, 397f
food labels and, 409–410, 410t
function in body, 397–398
homeostasis and, 398
low-sodium diet, 410
muscle contraction and, 397–398
nerve conduction and, 397–398, 398f
osteoporosis risk and, 424
in our food, 396–397, 396f
recommended intakes and, 403–406
role of, 398, 398f
toxicity and, 400
Sodium-potassium pump, 397, 397f
Solid foods, infant introduction to, 585
Soluble fiber, 118, 118f
Solutes, 386
South Beach diet, 276
Soy isoflavones, 380, 381f
Soy products, 235
Space flight, bone health and, 423
Special interest groups, dietary recommendations and, 61
Special Milk Program, 706t
Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), 706t
Sphincter, gastroesophageal, 80
Spina bifida, 328
Spinal compression fractures, 420
Spoilage, additives preventing, 665
Spongy bone, 419
Spontaneous abortion, 537
Spores, 646
Sports activities. *See* Athletes; Exercise
Sports anemia, 514, 514f
Sports bars, 422
St. John's wort, 487, 487f, 488t
Standards of identity, 666–667
Staphylococcus aureus, 643t, 645–646
Starches, 117, 117f
Starvation, defined, 686
Starvation symptoms, anorexia nervosa and, 290
StayWell supplement, 29
Steroid precursors, anabolic steroids and, 526
Sterols, 154
Stevia sweetener, 146t
Stomach
activity regulation and, 82, 82f
chyme and, 81
digestion and absorption and, 80–83
emotions and exercise and, 83
gastric juice and, 81
gastrin and, 82
meal composition and, 82, 82f
structure of, 81f, 91
Stretching, 494, 494f, 499
Stroke volume, cardiopulmonary endurance and, 493
Strontium-90, 659
Structural and regulatory molecule supplements, 484–485, 484f
Stunting, undernutrition and, 687, 687f
Subcutaneous fat, 249, 249f
Subsistence crops, 699
Sucralose, 146t
Sucrose. *See also* Sugars
characteristics of, 115f, 116
dental caries and, 133–134, 134f
as fat replacer, 187, 187f
Sudden infant death syndrome (SIDS), 558
Sugar alcohols, 147
Sugar-Busters, 276
Sugars
added sugars, 111, 112–114, 114f
children and, 591, 591f
consumption of, 111
limiting, 140–141, 141f

sugar chains, 116, 116f
sugar-sweetened drinks, 36
Sulfides, 378t
Sulforaphane, 378t, 379
Sulfur, 438, 439t
Sulfur compounds, 379
Summer Food Service Program, 706t
Sun exposure, vitamin D and, 360, 361f
Sunscreen, vitamin D synthesis and, 361f
Super-fortified foods, 306
Superbugs, genetically modified foods and, 681–682
Superoxide dismutase (SOD), 456
Superweeds, genetically modified foods and, 681–682
Supplemental Nutrition Assistance Program (SNAP), 632t, 706t, 707
Supplements. *See* Dietary supplements
Sustainable agriculture, 699, 700f
Sustainable Development Goals, 697–698, 698f
Sustainable diet choices, 700
Sweat losses, water and, 391–392
Sweet potatoes, 702, 702f
Sweeteners, 665f

T

Tannins, 378t, 416, 417f
Team Nutrition, 706t
Teenagers. *See* Adolescents
Teeth brushing, children and, 591
Television viewing, childhood obesity and, 592–594, 594f
Temperature, food safety and, 661–663
Temporary Assistance for Needy Families (TANF), 706t
Teratogens, pregnancy and, 555–556, 556f
Tetany, 429
Thermic effect of food (TEF), 256
Theory, 19f, 20
Thiamin (vitamin B1), 311–313
beriberi and, 311, 312, 312f
cooking and storage and, 312
deficiency and, 312
in diet, 311–312
functions in body, 312
MyPlate and, 311, 311f
recommended intake of, 313
supplements and, 313, 313t
thiamin pyrophosphate and, 312
toxicity and, 313
Wernicke-Korsakoff syndrome and, 312
Thiamin pyrophosphate, 312
Threshold effect, 637
Thrifty metabolism, 265–267
Thyroid hormones, 255, 466–467, 466f
Thyroid-stimulating hormone (TSH), 466, 467f
Tin, 475
Tissue formation, cells and, 74, 74f
Tobacco smoking. *See* Smoking
Tocopherol. *See* Vitamin E
Tolerable upper intake levels (ULs), 38f, 39
Tooth decay, fluoride and, 471–472
Total energy expenditure (TEE), 253, 496, 496f
Total parenteral nutrition (TPN), 96, 96f
Toxins
food-borne illness and, 636
genetically modified foods and, 680
Toxoplasma gondii, 643t
Trabecular bone, 419
Trace minerals
chromium, 469–470
copper, 458–460
elements with no dietary allowances established, 475
fluoride and, 470–473
importance of, 414
iodine, 464–468
iron, 444–453
manganese, 460–461
molybdenum, 473–475
in our diet, 444
in periodic table, 414f
selenium, 461–464
zinc, 454–458
Traditional breeding technology, 675
Trans fatty acids
cancer and, 178
food labeling and, 185–186
heart disease and, 174–175
properties of, 156f, 157
Transamination, 206, 206f
Transcription, protein synthesis and, 211, 211f
Transfer RNA (tRNA), 211
Transferrin, iron transport and, 446
Transgenic organisms, 675
Transit time, gastrointestinal tract and, 76
Translation, protein synthesis and, 211, 211f
Transport proteins, 217
Travelers' diarrhea, 644
Trichinella spiralis, 643t, 649
Triglycerides and fatty acids
body surface lubrication and, 166
cancer and, 178
cis vs. trans double bonds, 156f, 157
as energy source, 167, 168f
fatty acid chain length, 154–155
monounsaturated fatty acids, 156–157
omega-3 fatty acids, 155f, 157
omega-6 fatty acids, 157
partially hydrogenated oils, 157
polyunsaturated fatty acids, 157
properties and, 157, 158f
saturated fatty acids, 155–156, 155f
storage of, 257, 257t
synthesis of, 104–105
triglyceride formation and structure, 154, 154f
tropical oils, 155–156
unsaturated fatty acids, 155f, 156–157
Trimesters, pregnancy, 539
Tripeptides, 206
Tropical oils, 155–156
Tryptophan, 316–318, 316f
Tube feeding, 96
Tumor initiators, 137
Tumor promoters, 137
Twenty-four hour recall, dietary assessment and, 63, 63f
Type 1 diabetes, 128, 129f, 218
Type 2 diabetes, 129, 129f, 242, 579

U

Ulcers, 91, 92, 94, 95t
UN Disaster Relief Organization, 697
UN High Commissioner for Refugees, 697
Undernutrition and hunger
agricultural technology and, 698–699
cash crops and, 699
controlling population growth and, 698
cultural practices and, 691
cycle of, 686–687, 686f
education and fertility rates, 698, 698f
eliminating poverty and, 697–698
environment and, 699–700
famine and, 689–690, 689f
federal programs and, 706t, 707–708
food fortification and, 700–702
food self-sufficiency and, 698
food shortages and, 689–693
growth stunting and, 687, 687f
health and, 12–13, 13f
hunger at home, 703–708
impact of, 686–688
infant mortality rate and, 687
infection risk and, 687–688, 688f
international trade and, 699
iodine deficiency and, 694–695
iron deficiency and, 693–694
limited environmental resources and, 691
low birth weight and, 687
modern agriculture and, 691–693
nutrients of concern and, 695
ocean resource depletion and, 693, 693f
overpopulation and, 691, 691f
poor-quality diets and, 693–695
poverty and, 690–691, 690f
protein-energy malnutrition and, 693
providing education and, 702–703
renewable resources and, 691
short-term food aid and, 697, 697f
subsistence crops and, 699
supplementation and, 702
sustainable agriculture and, 699, 700f
sustainable choices and, 700
vitamin A deficiency and, 695
Underwater weighing, 247, 248f
Underweight, 244
UNICEF, 697
United States
body image and, 287–288
cycle of poverty and, 705, 705f
diet healthiness in, 6–8, 8f
disease and disability and, 706
education and, 704, 705f
federal malnutrition programs and, 706t, 707–708
food deserts and, 704, 704f
food insecurity causes and, 703–707, 703f
high nutrient needs and, 705
homelessness and, 704–705
limited health care and, 704
nutrition education and, 708
nutrition safety net and, 707
poverty and, 703–704, 704f
Unrefined carbohydrates, 110–111, 110f, 134
Urea, 214, 214f
Urinary losses, water and, 391, 392f
U.S. Department of Agriculture (USDA), 683
U.S. Food and Drug Administration (FDA), 639
U.S. Pharmacopeia (USP) Convention, 55
USP Dietary Supplement Verification Program (DSVP), 55

V

Vanadium, 454t, 475, 524t
Variant Creutzfeldt-Jakob disease, 649–650
Vegan diets, 232–233, 232t, 235, 235t, 334
Vegetables
  Dietary Guidelines for Americans and, 42
  phytochemical-rich diet and, 381, 382f
  recommendations and, 140
Vegetarian diets, 232–236
  benefits of, 232–233
  blood pressure and, 406
  choosing healthy, 234
  combining plant proteins and, 233, 233f
  dietary patterns and, 232t
  disease risks and, 232–233
  environmental benefits and, 692
  heart disease risk and, 173
  MyPlate and, 235, 236f
  nutrient risks and, 233–235
  teenagers and, 601–602, 602f
  vitamin and mineral deficiencies and, 233–235
Veins, 99
Vending machine food, food labeling and, 59
Very-low-birth weight infants, 538
Very-low-calorie diets, 275–276
Very-low-density lipoproteins (VLDL), 162–163, 162f, 169
Vibrio parahaemolyticus, 643t, 645
Vibrio vulnificus, 645
Villi (villus), 83, 83f
Virus-resistant papaya, 677, 677f
Viruses, 646–648, 647f
  infectious gastroenteritis and, 646, 647f
  noroviruses, 643t, 646–647
Visceral fat, 248–249, 249f
Vision, vitamin A and, 346, 349–350, 349f
Vitamin A
  anti-infective vitamin, 696
  beta-carotene and, 347–349, 348f, 351
  carotenoid toxicity and, 356–357, 356f
  carotenoids and, 347–349, 348f
  cell differentiation and, 347
  deficiency and, 351–355, 702
  in the diet, 347
  digestive tract and, 348
  as a drug, 357
  fast-food meals and, 353
  forms of, 347, 348f
  functions in body, 348–351
  gene expression and, 350–351, 350f
  golden rice and, 352
  growth and, 355
  hypercarotenemia and, 356–357, 356f
  immune function and, 354
  keratinization and, 354
  keratomalacia and, 354
  life cycle and, 351
  meeting needs and, 351–357
  MyPlate and, 347, 347f
  night blindness and, 350, 354
  recommended intake and, 355
  reproduction and, 355
  retinoids and, 347–349, 348f
  retinol activity equivalents, 355, 355f
  retinol-binding protein and, 348
  rhodopsin and, 349–350
  sources and functions, 346–351
  supplements and, 356–357, 357t
  toxicity and, 356–357, 357f
  undernutrition and hunger and, 695
  vision and, 346, 349–350, 349f
  xerophthalmia and, 354, 354f
Vitamin B_1. *See* Thiamin
Vitamin B_6, 321–325
  anemia and, 322
  cardiovascular disease and, 324, 324f
  carpal tunnel syndrome and, 325
  coenzyme functions of, 322, 323f
  deficiency and, 322–323
  in the diet, 321–322
  functions in body, 322
  heart disease and, 177
  homocysteine and, 324, 324f
  immunity and, 325
  MyPlate and, 321–322, 322f
  nerve functions and, 322, 323f
  neurological symptoms and, 322
  oral contraceptives and, 323
  premenstrual syndrome and, 325
  protein and, 323
  pyridoxal phosphate and, 322
  recommended intake and, 324
  supplements and, 313t, 325
  toxicity and, 324–325
Vitamin B_{12}, 331–334
  atrophic gastritis and, 333–334
  deficiency, 333–334
  in the diet, 331–332
  in digestive tract, 332, 332f
  folate and, 333–334
  functions in body, 333
  heart disease and, 177
  infants and, 566
  intrinsic factor and, 332
  life cycle and, 334
  MyPlate and, 331–332, 331f
  parietal cells and, 332
  pernicious anemia and, 331, 334
  pregnancy and, 334, 548
  recommended intake and, 334
  supplemental folic acid and, 334
  supplements and, 313t, 334
  toxicity and, 334
  vegan diets and, 233, 334
Vitamin B complex supplements, 313t
Vitamin C
  as antioxidant, 336–337, 337f
  cancer and, 339
  cardiovascular disease and, 338–339
  cholesterol and, 339
  cigarette smoking and, 338
  collagen synthesis and, 336, 336f
  common cold and, 338, 339f
  deficiency and, 8, 337
  in the diet, 335–336
  functions in body, 336–337
  iron absorption and, 337, 445–446
  life cycle and, 338
  MyPlate and, 335–336, 335f
  pregnancy and, 338
  recommended intake and, 337–338
  scurvy and, 335, 337, 338f
  supplements and, 313t, 338–339
  toxicity and, 338
Vitamin D, 357–362
  age-related bone loss and, 421–422
  athletes and, 514–515
  bone health and, 358–359
  breast-fed infants and, 362
  calcium bioavailability and, 429
  cholecalciferol and, 357
  dark skin pigmentation and, 361, 361f
  deficiency and, 360–361
  in the diet, 357
  food intake and, 362
  fortified milk and, 584
  functions in body, 357–360, 360f
  health protection and, 359
  infants and children and, 566, 566f, 583
  life cycle and, 361
  magnesium absorption and, 436
  meeting needs and, 362
  MyPlate and, 357, 357f
  obesity and, 362
  older adults and, 361, 624
  osteomalacia and, 360–361
  osteoporosis risk and, 424
  parathyroid hormone and, 358
  phosphorus absorption and, 325
  pregnancy and, 361
  recommended intake and, 361
  rickets and, 360, 360f
  skin pigmentation and, 566, 566f
  sun exposure and, 360, 361f, 362
  supplements and, 357t, 362
  synthesis and activation, 358, 359f
  toxicity and, 362
Vitamin E, 363–366
  alpha-tocopherol and, 363–364
  antioxidant function and, 364, 365f, 366
  cell membrane protection and, 364–365
  cystic fibrosis and, 365
  deficiency and, 365
  in the diet, 363–364
  fat absorption and, 364
  functions in body, 364–365
  hemolytic anemia and, 365
  isomers and, 363–364
  life cycle and, 365–366
  MyPlate and, 363–364, 363f
  pregnancy and, 366
  recommended intake and, 366
  supplements and, 357t, 364, 364f, 366
  toxicity and, 366
Vitamin K, 366–371
  blood clotting and, 367–368, 368f
  coagulation and, 366–367
  deficiency and, 367–368
  dicumarol and, 369
  in the diet, 366–367
  functions in body, 367
  infants and, 566
  injections and surgery, 368
  life cycle and, 369
  MyPlate and, 366–367, 367f
  newborns and, 369
  prothrombin and, 367
  recommended intake and, 368
  supplements and, 357t, 368
  toxicity and, 368
  warfarin and, 369
Vitamins. *See also* Fat-soluble vitamins; Water-soluble vitamins
  adolescents and, 598
  antioxidants, 308
  athlete requirements and, 512–515

bioavailability and, 307–308
children and, 587–588
deficiencies and, 309
definition of, 304
dietary supplements and, 305
in digestive tract, 307–308, 307f
energy metabolism and, 308, 309f
enzyme activity and, 308, 308f
ergogenic aids and, 523–525
food labels and, 310, 310f
fortified breakfast cereals and, 305, 305f
fortified foods and, 304–305
functions of, 11, 308
meeting needs and, 309–310
MyPlate and, 304, 305f
natural food sources of, 304
older adults and, 622–625, 623f
in our diet, 304–306
pregnancy and, 545, 545f
preservation in foods, 310, 310t
provitamins, 308
recommended intakes and, 310
storage and excretion, 308
super-fortified foods and, 306
vitamin precursors, 308
VO_2max, *See* Aerobic capacity
Vomiting, 80, 95t

W

Waist circumference, 249, 249f
Warfarin, 369
Waste elimination, 105–106, 105f
Water
absorption and, 390
acid-base balance and, 387
blood pressure and, 388
bodily functions of, 386–387
body temperature regulation and, 386–387, 387f
bottled water, 395
dehydration and, 392–393, 393f
distribution throughout body, 387–389, 389f
evaporative losses and, 391
fecal losses and, 391
hyponatremia and, 393
infants and children and, 564–565, 582
intake and, 390–391, 391f
intoxication, 393
lactation and, 561
losses and, 391–392
lubrication and protection and, 386
material transport and, 386
metabolic reactions and, 387
MyPlate and, 390, 390f
nutrition and, 10–11
older adults and, 622
osmosis and, 388–389, 389f
overhydration and, 393
polar nature of, 386, 386f
pregnancy and, 545
recommended intake of, 394, 394f
regulating loss of, 392, 392f
rehydration and, 393, 393f
as solvent, 386
summary of, 400t
sweat losses and, 391–392
urinary losses and, 391, 392f
water balance, 389–394, 390f
Water-soluble vitamins, 304, 304f
biotin, 319–320
folate (folic acid), 325–331
niacin, 315–319
in our diet, 304–306
pantothenic acid, 320–321
riboflavin, 314–315
summary of, 340t
thiamin (vitamin B_1), 311–313
vitamin B_6, 321–325
vitamin B_{12}, 331–334
vitamin C, 335–339
Wear and tear, aging and, 611
Weight. *See* Body weight; Weight management
Weight management, 268–272
balancing calories and, 42
bariatric surgery and, 278–281, 280f
behavior modification and, 271–272, 271f
carbohydrates and, 134, 134f
drugs and supplements and, 277–278, 480t
energy intake and, 270–271
energy intake reduction methods, 273–277
excess weight risks, 268–269, 268f
gastric banding and, 280
gastric bypass and, 280–281, 280f
gastric sleeve surgery and, 280
genetics and lifestyle, 273
healthy weight gain, 511
healthy weight loss, 510
ideal program, 270–272
life stage and, 269
liposuction and, 281
obesogenic environment and, 272
older adults and, 625
physical activity and, 271, 496, 496f
pregnancy and, 269
prescription and nonprescription drugs and, 277
unhealthy weight-loss practices, 510
weight cycling and, 270, 270f
weight gain suggestions, 272
weight loss approaches and, 272–281
weight loss challenges, 269–270
weight loss goals and, 269
yo-yo dieting and, 270, 279f
Wernicke-Korsakoff syndrome, 312
Wet beriberi, 312
Wheat allergy, 89–90
Wheat bran, 118
Whole grains
nutrient composition and, 111, 111f
phytochemical-rich diet and, 382
recommendations and, 140
WIC Farmers' Market Nutrition Program, 706t
Wilson's disease, 458
World Bank, 697
World hunger. *See* Undernutrition and hunger

X

Xerophthalmia, 354, 354f, 695, 695f

Y

Yersinia enterocolitica, 643t
Yo-yo dieting, 270, 270f
Yogurt, calcium and, 432

Z

Zeaxanthin, 485
Zinc, 454–458, 454t, 474t
absorption and, 455, 456f
acrodermatitis enteropathica and, 457–458
adolescents and, 600
cellular activities and, 456
cold symptoms and, 458, 458f
copper absorption and, 459, 459f
deficiency and, 457, 695
in the diet, 454
in digestive tract, 454–455
functions in body, 455–456
gene expression and, 456, 457f
genetic abnormalities and, 458
immune function and, 457
life cycle and, 457
lozenges and, 458, 458f
metallothionein and, 455
MyPlate and, 454, 455f
older adults and, 624
pregnancy and, 457, 548
recommended intake and, 457
superoxide dismutase and, 456
supplements and, 457–458
toxicity and, 457
vegetarian diets and, 235
Wilson's disease and, 458
zinc fingers, 456, 457f
Zone diet, 276
Zygote, 536

Dietary Reference Intakes: Tolerable Upper Intake Levels (UL[a]): Vitamins

Life Stage Group	Vitamin A (μg/day)[b]	Vitamin C (mg/day)	Vitamin D (μg/day)	Vitamin E (mg/day)[c,d]	Vitamin K	Thiamin	Riboflavin	Niacin (mg/day)[d]	Vitamin B_6 (mg/day)	Folate (μg/day)[d]	Vitamin B_{12}	Pantothenic Acid	Biotin	Choline (g/day)	Carotenoids[e]
Infants															
0–6 mo	600	ND[f]	25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6–12 mo	600	ND	38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Children															
1–3 y	600	400	63	200	ND	ND	ND	10	30	300	ND	ND	ND	1.0	ND
4–8 y	900	650	75	300	ND	ND	ND	15	40	400	ND	ND	ND	1.0	ND
Males, Females															
9–13 y	1,700	1,200	100	600	ND	ND	ND	20	60	600	ND	ND	ND	2.0	ND
14–18 y	2,800	1,800	100	800	ND	ND	ND	30	80	800	ND	ND	ND	3.0	ND
19–70y	3,000	2,000	100	1,000	ND	ND	ND	35	100	1,000	ND	ND	ND	3.5	ND
>70 y	3,000	2,000	100	1,000	ND	ND	ND	35	100	1,000	ND	ND	ND	3.5	ND
Pregnancy															
14–18 y	2,800	1,800	100	800	ND	ND	ND	30	80	800	ND	ND	ND	3.0	ND
19–50 y	3,000	2,000	100	1,000	ND	ND	ND	35	100	1,000	ND	ND	ND	3.5	ND
Lactation															
14–18 y	2,800	1,800	100	800	ND	ND	ND	30	80	800	ND	ND	ND	3.0	ND
19–50 y	3,000	2,000	100	1,000	ND	ND	ND	35	100	1,000	ND	ND	ND	3.5	ND

[a]UL = The maximum level of daily nutrient intake that is likely to pose no risk of adverse effects. Unless otherwise specified, the UL represents total intake from food, water, and supplements. Due to lack of suitable data, ULs could not be established for vitamin K, thiamin, riboflavin, vitamin B_{12}, pantothenic acid, biotin, or carotenoids. In the absence of ULs, extra caution may be warranted in consuming levels above recommended intakes.

[b]As preformed vitamin A only.

[c]As α-tocopherol; applies to any form of supplemental α-tocopherol.

[d] The ULs for vitamin E, niacin, and folate apply to synthetic forms obtained from supplements, fortified foods, or a combination of the two.

[e]β-Carotene supplements are advised only to serve as a provitamin A source for individuals at risk of vitamin A deficiency.

[f]ND = Not determinable due to lack of data of adverse effects in this age group and concern with regard to lack of ability to handle excess amounts. Source of intakes should be from food only to prevent high levels of intake.

Source: Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences. Available online at www.nap.edu. Reprinted with permission from *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements*, 2006, by the National Academy of Sciences, Washington, D.C. Institute of Medicine, Food and Nutrition Board, Dietary Reference Intakes for Calcium and Vitamin D (2011), National Academies Press, Washington. DC, 2011.

Dietary Reference Intakes: Tolerable Upper Intake Levels (UL[a]): Minerals

Life Stage Group	Arsenic[b]	Boron (mg/day)	Calcium (g/day)	Chromium	Copper (μg/day)	Fluoride (mg/day)	Iodine (μg/day)	Iron (mg/day)	Magnesium (mg/day)[c]	Manganese (mg/day)	Molybdenum (μg/day)	Nickel (mg/day)	Phosphorus (g/day)	Selenium (μg/day)	Silicon[d]	Vanadium (mg/day)[e]	Zinc (mg/day)	Sodium (g/day)	Chloride (g/day)	Potassium
Infants																				
0–6 mo	ND[f]	ND	1.0	ND	ND	0.7	ND	40	ND	ND	ND	ND	ND	45	ND	ND	4	ND	ND	ND
6–12 mo	ND	ND	1.5	ND	ND	0.9	ND	40	ND	ND	ND	ND	ND	60	ND	ND	5	ND	ND	ND
Children																				
1–3 y	ND	3	2.5	ND	1,000	1.3	200	40	65	2	300	0.2	3	90	ND	ND	7	1.5	2.3	ND
4–8 y	ND	6	2.5	ND	3,000	2.2	300	40	110	3	600	0.3	3	150	ND	ND	12	1.9	2.9	ND
Males, Females																				
9–13 y	ND	11	3.0	ND	5,000	10	600	40	350	6	1,100	0.6	4	280	ND	ND	23	2.2	3.4	ND
14–18 y	ND	17	3.0	ND	8,000	10	900	45	350	9	1,700	1.0	4	400	ND	ND	34	2.3	3.6	ND
19–30 y	ND	20	2.5	ND	10,000	10	1,100	45	350	11	2,000	1.0	4	400	ND	1.8	40	2.3	3.6	ND
31–50 y	ND	20	2.5	ND	10,000	10	1,100	45	350	11	2,000	1.0	4	400	ND	1.8	40	2.3	3.6	ND
51–70 y	ND	20	2.0	ND	10,000	10	1,100	45	350	11	2,000	1.0	4	400	ND	1.8	40	2.3	3.6	ND
>70 y	ND	20	2.0	ND	10,000	10	1,100	45	350	11	2,000	1.0	3	400	ND	1.8	40	2.3	3.6	ND
Pregnancy																				
14–18 y	ND	17	3.0	ND	8,000	10	900	45	350	9	1,700	1.0	3.5	400	ND	ND	34	2.3	3.6	ND
19–50 y	ND	20	2.5	ND	10,000	10	1,100	45	350	11	2,000	1.0	3.5	400	ND	ND	40	2.3	3.6	ND
Lactation																				
14–18 y	ND	17	3.0	ND	8,000	10	900	45	350	9	1,700	1.0	4	400	ND	ND	34	2.3	3.6	ND
19–50 y	ND	20	2.5	ND	10,000	10	1,100	45	350	11	2,000	1.0	4	400	ND	ND	40	2.3	3.6	ND

[a]UL = the maximum level of daily nutrient intake that is likely to pose no risk of adverse effects. Unless otherwise specified, the UL represents total intake from food, water, and supplements. Due to lack of suitable data, ULs could not be established for arsenic, chromium, silicon, and potassium. In the absence of ULs, extra caution may be warranted in consuming levels above recommended intakes.

[b]Although the UL was not determined for arsenic, there is no justification for adding arsenic to food or supplements.

[c]The ULs for magnesium represent intake from a pharmacological agent only and do not include intake from food and water.

[d]Although silicon has not been shown to cause adverse effects in humans, there is no justification for adding silicon to supplements.

[e]Although vanadium in food has not been shown to cause adverse effects in humans, there is no justification for adding vanadium to food and vanadium supplements should be used with caution. The UL is based on adverse effects in laboratory animals and this data could be used to set a UL for adults but not children and adolescents.

[f]ND = Not determinable due to lack of data of adverse effects in this age group and concern with regard to lack of ability to handle excess amounts. Source of intake should be from food only to prevent high levels of intake.

Source:Dietary Reference Intake Tables: The Complete Set. Institute of Medicine, National Academy of Sciences. Available online at www.nap.edu. Reprinted with permission from *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements* , 2006, by the National Academy of Sciences, Washington, D.C. Institute of Medicine, Food and Nutrition Board. Dietary Reference Intakes for Calcium and Vitamin D (2011), National Academies Press, Washington, DC, 2011.

Dietary Reference Intake Values for Energy: Estimated Energy Requirement (EER) Equations and Values for Active Individuals by Life Stage Group

Life Stage Group	EER Prediction Equation	EER for Active Physical Activity Level (kCal\day)[a]	
		Male	Female
0–3 mo	EER = (89 × weight of infant in kg − 100) + 175	538	493 (2 mo)[c]
4–6 mo	EER = (89 × weight of infant in kg − 100) + 56	606	543 (5 mo)[c]
7–12 mo	EER = (89 × weight of infant in kg − 100) + 22	743	676 (9 mo)[c]
1–2 y	EER = (89 × weight of infant in kg − 100) + 20	1046	992 (2 y)[c]
3–8 y			
Male	EER = 88.5 − (61.9 × Age in yrs) + PA[b][(26.7 × Weight in kg) + (903 × Height in m)] + 20	1742 (6 y)[c]	
Female	EER = 135.3 − (30.8 × Age in yrs) + PA[b][(10.0 × Weight in kg) + (934 × Height in m)] + 20		1642 (6 y)[c]
9–13 y			
Male	EER = 88.5 − (61.9 × Age in yrs) + PA[b][(26.7 × Weight in kg) + (903 × Height in m)] + 25	2279 (11 y)[c]	
Female	EER = 135.3 − (30.8 × Age in yrs) + PA[b][(10.0 × Weight in kg) + (934 × Height in m)] + 25		2071 (11 y)[c]
14–18 y			
Male	EER = 88.5 − (61.9 × Age in yrs) + PA[b][(26.7 × Weight in kg) + (903 × Height in m)] + 25	3152 (16 y)[c]	
Female	EER = 135.3 − (30.8 × Age in yrs) + PA[b][(10.0 × Weight in kg) + (934 × Height in m)] + 25		2368 (16 y)[c]
19 and older			
Males	EER = 662 − (9.53 × Age in yrs) + PA[b][(15.91 × Weight in kg) + (539.6 × Height in m)]	3067 (19 y)[c]	
Females	EER = 354 − (6.91 × Age in yrs) + PA[b][(9.36 × Weight in kg) + (726 × Height in m)]		2403 (19 y)[c]
Pregnancy			
14–18 y			
1st trimester	Adolescent EER + 0		2368 (16 y)[c]
2nd trimester	Adolescent EER + 340 kcal		2708 (16 y)[c]
3rd trimester	Adolescent EER + 452 kcal		2820 (16 y)[c]
19–50 y			
1st trimester	Adult EER + 0		2403 (19 y)[c]
2nd trimester	Adult EER + 340 kcal		2743 (19 y)[c]
3rd trimester	Adult EER + 452 kcal		2855 (19 y)[c]
Lactation			
14–18 y			
1st 6 mo	Adolescent EER + 330 kcal		2698 (16 y)[c]
2nd 6 mo	Adolescent EER + 400 kcal		2768 (16 y)[c]
19–50 y			
1st 6 mo	Adult EER + 330 kcal		2733 (19 y)[c]
2nd 6 mo	Adult EER + 400 kcal		2803 (19 y)[c]

[a] The intake that meets the average energy expenditure of active individuals at a reference height, weight, and age.

[b] See table entitle "Physical Activity Coefficients (PA Values) for Use in EER Equations" to determine the PA value for various ages, genders, and activity levels.

[c] Value is calculated for an individual at the age in parentheses.

Source: Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Protein and Amino Acids.* Washington, DC: National Academies Press, 2002/2005.

Physical Activity Coefficients (PA Values) for Use in EER Equations

Age and Gender	Sedentary	Low Active	Active	Very Active
3 to 18 y				
Boys	1.00	1.13	1.26	1.42
Girls	1.00	1.16	1.31	1.56
≥19 y				
Men	1.00	1.11	1.25	1.48
Women	1.00	1.12	1.27	1.45

Source: Institute of Medicine, Food and Nutrition Board. "Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein, and Amino Acids." Washington, D.C.: National Academies Press, 2002.

WILEY END USER LICENSE AGREEMENT

Go to www.wiley.com/go/eula to access Wiley’s ebook EULA.