SECOND EDITION

Sports Nutrition for Paralympic Athletes

Elizabeth Broad

CRC Press
Taylor & Francis Group

Sports Nutrition for Paralympic Athletes

Second Edition

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

Sports Nutrition for Paralympic Athletes

Second Edition

Edited by

Elizabeth Broad

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper

International Standard Book Number-13: 978-1-138-58900-1 (Hardback)

Library of Congress Cataloging-in-Publication Data

Names: Broad, Elizabeth, editor.
Title: Sports nutrition for paralympic athletes / Elizabeth Broad.
Description: Second edition. | Boca Raton, Florida : CRC Press, [2019] |
Includes bibliographical references and index.
Identifiers: LCCN 2018057046| ISBN 9781138589001 (hardback : acid-free paper)
| ISBN 9780429491955 (ebook)
Subjects: LCSH: Physical education for people with disabilities. | Physical
fitness--Nutritional aspects. | Sports for people with disabilities.
Classification: LCC GV445 .S685 2019 | DDC 796.04/56--dc23
LC record available at https://lccn.loc.gov/2018057046

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Contents

Foreword

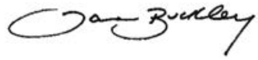
Lord Sebastian Coe declared that the 2012 London Paralympic Games resulted in a "seismic effect in shifting public attitudes" about sport for athletes with an impairment. The Paralympic Movement can no longer be ignored as a legitimate competitive sporting event. Sports science and performance management supporting these athletes is a rapidly growing body of knowledge. Only in recent years has a comprehensive handbook been published on sports medicine for Paralympic athletes.

What fuels our Paralympians nutritionally is vitally important, and this book addresses this essential area. Currently the most well-credentialed and acknowledged person in sports nutrition for the impaired is Dr. Elizabeth (Liz) Broad. I have worked with Liz for nearly 20 years, and she has demonstrated an unrelenting dedication to improving the science base in this area. I have been privileged to work and collaborate with Liz both during and since my retirement from my 25 years of involvement as an Australian Paralympic team physiotherapist and International Paralympic classifier.

Liz has provided a much-needed volume, now in its second edition, on an essential part of any athlete's competitive edge. As one of the most prolific authors in this area, she has assembled an international team of collaborators, all experts in this field. *Sports Nutrition for Paralympic Athletes* provides information on the broad subcategories of all physical impairments (grouped as spinal cord injuries, amputees, cerebral palsy and other physical impairments), along with vision impairments, hearing impairments and intellectual impairments. Specific areas such as body composition, supplements and practical issues are discussed comprehensively. Case studies enhance and illustrate a direct and firsthand application to managing Paralympic athletes. This second edition has been expanded with new chapters, case studies and cutting-edge research. This edition is additionally enhanced by Liz bringing a wealth of current practical experience in her capacity as U.S. Paralympics Senior Sport Dietitian (for the past five years).

While it might be argued that, for the most part, sports nutrition for Para athletes may be no different from that for regular athletes, the required expertise to ensure the best science is utilised in some areas needs to be explored and highlighted. Hopefully, this book will challenge and stimulate current and future research in this area to improve the delivery of this intrinsic component of athlete preparation.

Sports Nutrition for Paralympic Athletes is an essential addition to the resources for anyone interested in the sports nutrition requirements for our Paralympic athletes. Sports nutrition can be the difference in being competitive and making the podium. As a resource, this book is vital in the armoury of sports medicine teams, and with the Paralympic profile rapidly increasing, it will be required reading for professionals endeavouring to give their athletes a competitive edge.



Jane Buckley
Australian Paralympic Team Physiotherapist 1984–2000
IPC International Classifier 1992–2009
Medical Director of the Australian Paralympic Team for Sydney 2000

Preface

Individuals with an impairment constantly have to adapt in order to progress in the world we live in – our challenge is to come up with ideas as to how they can do this in sport. The scope of this book was not to rewrite a range of excellent, comprehensive resources already devoted to various aspects of sports nutrition, but rather to provide a more expansive set of knowledge, considerations and tips that a practitioner might need to consider when applying this knowledge to an athlete with an impairment. In doing so, I believed it was important to provide as much background information about impairments and para-sport as was necessary and practical. In my professional experience, I have become very comfortable with the fact that Para athletes are "an n of 1" who have their own unique needs and challenges and have embraced the problem-solving process that is often required to help them optimise and adapt to training, compete at their desired level (whatever that may be), remain healthy and, above all, enjoy their sport. If there's one thing I've learnt, it's NEVER to think that something may NOT be possible.

In the preparation of this second edition, I have been delighted to realise how much has been invested in some areas of research on Para athletes in the past five years. At the same time, I am reminded of how little we still know in other areas. The contributors to this book are leading the way in searching for answers, and we encourage you all to join the ride.

This book is aimed at students interested in working within para-sport and sports nutrition, sports practitioners and coaches who are searching for information to help them adapt their practise if necessary, and researchers who may want some ideas as to some cool research projects to involve their students in! Hopefully, it's also relevant to athletes who are looking for more detailed information to support their endeavours.

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

Acknowledgments

When Randy Brehm approached me to undertake the second edition of this book, I was surprised. I knew it was always going to be a niche publication, but this showed that it was valued more than I expected; so, for all the readers, this would not have been undertaken without you! I would like to thank Randy Brehm (Senior Editor) and Paul Boyd at Taylor & Francis/CRC Press and Pam Tagg at Nova Techset for their support throughout the production process.

This book could not have been possible without the support of all the contributors, athletes, coaches and scientists. Thank you all for your passion, time and willingness to share knowledge, especially in a Paralympic year! The U.S. Olympic Committee, and especially U.S. Paralympics, are recognised for providing me with one of the rarest opportunities for the past five years – to work full time with Paralympic athletes and sports programs. It's definitely been a journey of continued growth and experience within an incredibly supportive environment.

To my husband, Darren, for your ever-present support, encouragement to stretch myself, and red penning. To my family and friends, for everything that you do to tolerate my crazy endeavours across the globe, I love you all!

Finally, I devote this book to all the passionate and committed Paralympic athletes and coaches I have worked with over the past 25 years. I have learnt so much from you – and that goes well beyond the scope of sports nutrition practise. You have my most humble appreciation.

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

Editor

Dr Elizabeth Broad, BSc, Dip.Nutr.Diet., M.App.Sc., PhD, Level 3 Anthropometrist, APD, FSDA. Dr Broad has been a sports dietitian for over 25 years, working with elite and developing athletes from a wide range of sports in Australia, the UK and the USA. Dr Broad's interest in athletes with an impairment was sparked early, through working with the Australian Institute of Sport athletics program (Paralympic athletes) and undertaking her master's dissertation on "The Effects of Heat on Shooting Performance in Wheelchair Shooters." While having always worked in some capacity with athletes with an impairment, she has been fortunate enough to have now spent over seven years in a full-time capacity with Para athletes. She has been fortunate enough to work at two Olympic Games with canoe/kayak, two Winter Paralympic games (with Team USA) and two Summer Paralympic Games (London with Team Australia, Rio with Team USA).

In addition to sports nutrition, Dr Broad has experience in exercise science and team management and has lectured in sports nutrition and in biochemistry of exercise at several universities. She has also authored several book chapters and lay and scientific publications.

Dr Broad is currently working as the Senior Sport Dietitian, U.S. Paralympics, at the U.S. Olympic Committee.

Contributors

Elizabeth Broad
U.S. Paralympics/U.S. Olympic Committee
Chula Vista, California

Louise M. Burke
Australian Institute of Sport
Canberra, Australia

Siobhan Crawshay
Australian Paralympic Committee
Melbourne, Victoria, Australia

Victoria Goosey-Tolfrey
Peter Harrison Centre for Disability Sport
Loughborough, England

Terri Graham-Paulson
English Institute of Sport
Loughborough, England

Amos Laar
University of Ghana
Legon, Ghana

Emerald Lin
Weill Cornell Medicine
New York, New York

Michelle Minehan
University of Canberra
Canberra, Australian Capital Territory, Australia

Nida Naushad
Yale University
New Haven, Connecticut

Daniel Paduan Joaquim
Brazilian Paralympic Committee
São Paulo, Brazil

Claudio Perret
Swiss Paraplegic Centre
Nottwil, Switzerland

Mike Price
Coventry University
Coventry, England

Kelly Pritchett
Central Washington University
Ellensburg, Washington

Robert Pritchett
Central Washington University
Ellensburg, Washington

Claudia Ridel Juzwiak
Universidade Federal de São Paulo
Santos, Brazil

Jacque Scaramella
U.S. Paralympics/U.S. Olympic Committee
Chula Vista, California

Greg Shaw
Freelance Sports Dietitian
Brisbane, Queensland, Australia

Gary Slater
University of the Sunshine Coast
Maroochydore, Queensland, Australia

Christine Townsend
New York Presbyterian
New York, New York

Yetsa Tuakli-Wosornu
Yale University
New Haven, Connecticut

Peter Van de Vliet
International Paralympic Committee
Bonn, Germany

Contributions by Way of Commentary

Scientists/Practitioners
Professor Luc Van Loon, Maastricht University
Professor Kevin Tipton, Stirling University
Ben Stephenson, Loughborough University
Dr Sophie Killer, British Athletics
Victoria Moore, Para-athletics lead physiotherapist, Australia

Coaches
Iryna Dvoskina, Athletics
Adam Bleakney, Athletics
Jenni Banks, Athletes/cycling
Sam Gardner, Strength and conditioning
Eileen Carey, Nordic ski

Athletes
Lex Gillette, Athletics (USA)
Steve Serio, Wheelchair basketball (USA)
Carmen Lim, Swimming (Malaysia)
AJ, Para canoe (Australia)
Charl Parkin, Swimming and triathlon (South Africa)
Allysa Seely, Para triathlon (USA)

Disclaimer
The material, views and information in this book are those of the authors, presented on their own behalf, and do not necessarily reflect those of their employers or their affiliates. All information is correct at time of publication.

List of Figures

List of Tables

Abbreviations

AB	able-bodied
ADL	activities of daily living
ADP	air-displacement plethysmography
BIA	bioelectrical impedance analysis
BM	body mass
CHO	carbohydrate
CP	cerebral palsy
DXA	dual x-ray absorptiometry
EA	energy availability
EE	energy expenditure
FFM	fat-free mass
GI	glycaemic index
IPC	International Paralympic Committee
LEA	low energy availability
MS	multiple sclerosis
RMR	resting metabolic rate
SCI	spinal cord injury (injured)
TEA	thermic effect of activity
TEF	thermic effect of feeding

1 Introduction

Elizabeth Broad

CONTENTS

"There is little point in training hard without taking advantage of the opportunities that nutrition support can offer" (Maughan and Burke 2011). This statement started the first edition of this book and remains equally valid five years later. Our knowledge of the human body, its responses to exercise and the nutrition-related factors that enable an athlete to become fitter, faster and stronger have evolved substantially over the past three decades. Present-day recommendations are individualised to the athlete's specific goals and periodised according to the time of the week, macrocycle and stage of an athlete's development and sporting career. The core goals are to maximise the adaptations to training in order to then optimise performance on the day of competition. These outcomes are underpinned by the need to achieve an appropriate body composition, promote health and well-being, minimise the time lost to illness and injury and maintain the enjoyment of food. The goals of sports nutrition can be applied across the spectrum of athletic endeavour, from the developmental athlete through to the "elite" performer, as well as the individual who exercises for general fitness and weight control. In this way, our definition of *athlete* is an expansive one that describes any individual who is undertaking regular exercise or involved in sport, regardless of the intended outcomes.

Sport for Para athletes has grown progressively over the last century from its early beginnings as a component of rehabilitation to improve both functionality as well as quality of life following injury. The opportunities for individuals with any form of impairment to participate in sport and exercise have increased substantially over recent decades, with specialist coaches/trainers, sporting events, national and international competitions and opportunities to become an elite-level athlete competing at the Paralympic Games. As a consequence, Para athletes are now undertaking committed training programs which are similar to those undertaken by their able-bodied counterparts at a similar age and developmental stage, and are achieving high standards of competition performances. However, in the majority of countries, opportunities for Para athletes to receive funding to support them competing at an elite level have not kept pace with those of able-bodied athletes. Therefore, it is not uncommon to have athletes at the elite level who still work full time, who have limited opportunities to train regularly with their teammates and who have to travel long distances (including overseas) to find opportunities to compete. In addition, many coaches are still learning how best to balance training type, frequency and load required to optimise training for an athlete whose physiological capabilities may be altered. Creating a support team that includes the coach and athlete can be useful for generating ideas around how best to manage all components of training, including their sports nutrition requirements.

The benefits of specialised nutrition support for achieving training and competition goals cannot be overstated. The role of the sports dietitian/nutritionist is to assess an individual athlete's current dietary practises and provide advice regarding how they can be modified and improved to optimise training capability, training adaptations, body composition goals and competition performance. Adapting general sports nutrition guidelines to develop individual, periodised approaches for Para athletes is no different to those for an able-bodied athlete. Practitioners should aim to develop a sound knowledge of both the athlete's impairment and the events in which they compete so that the specific physiological requirements, practical challenges and culture of the sport can be appreciated and integrated into the sports nutrition plan. The plan must be fine-tuned to the individual through practise and feedback. Applying sports nutrition principles to some forms of impairment (such as vision impairment, high-functioning cerebral palsy, intellectual impairment) and sporting activities is fairly straightforward, since the athlete's physiological functioning is not substantially different to that of an able-bodied individual. In contrast, some impairment types involve substantially altered physiological and physical capabilities, and many para-sports have unique physiological demands (such as goalball, boccia, wheelchair rugby), all of which have very little research available to help understand how best to apply sports nutrition principles. This book aims to assist practitioners working with Para athletes by presenting the research that is available and providing practical tips and guidelines for problem solving when research is not available.

1.1 OUTLINE OF THIS BOOK

The book commences with a description and short history of sport for athletes with an impairment (or para-sports, both of which are the accepted terms; International Paralympic Committee 2017), including the concept of classification. It is acknowledged that not all Para athletes will be participating at a level that requires them to be classified; however, the principles are useful to understand for individuals who may be involved in organising, running or officiating in local sporting events where individuals with an impairment may participate.

Chapter 3 reviews current principles of sports nutrition for both training and competition. Since there are very few scientific studies specifically undertaken on Para athletes, this chapter will outline the guidelines developed for able-bodied athletes and highlight areas that can be challenging for Para athletes. Chapters 4 and 5 address in more detail energy availability and cooling and hydration for Para athletes. Subsequently, Chapters 5 to 11 will further investigate nutrition challenges within specific classes of impairment and outline solutions.

Chapters 12 to 15 then explore areas associated with sport and exercise which a sports nutrition practitioner may require a more in-depth understanding of, or utilise tools associated with, in their assessment of athletes' needs and may influence the advice which is given.

New to this edition (Appendix A) is an explanation of each Paralympic sport – the classes of athletes eligible to compete, an outline of the sport itself and its key rule differences compared to its able-bodied counterpart (if there is one). Considering the inclusion of sports in major games changes over time, readers are advised to seek updates via the International Paralympic Committee (IPC) website (www.paralympic.org). Since many Para athletes are unique, case studies and comments from athletes and coaches are utilised throughout the book to provide practical examples of the process which may be required when advising an athlete. In addition, commentaries from experts in the field of sports nutrition research are presented to answer specific questions on how their field of research could be adapted to this population. Throughout this book, it is assumed readers have a pre-existing understanding of basic exercise physiology, exercise biochemistry and nutrition – where this is not the case, several key readings have been recommended. While we have attempted to outline the majority of impairments that practitioners are likely to come across, it is acknowledged that not every single impairment can be explored. However, it is our hope that we have provided sufficient detail and breadth of information that the practitioner understands where to look when presented with a more unusual case.

COMMENTARY BOX 1.1

ATHLETE INSIGHT: What do you believe are the biggest challenges to you in being able to train consistently and optimise your sporting performance?

> *Time management.* As I am both a full-time athlete as well as student, I find myself struggling at times, trying to juggle both sporting and academic excellence. All of my time that hasn't been already used up for training or studying would be contributed to my sleep schedule. Despite the fact that having sufficient sleep is vital for maintaining my sporting performance at the highest level, it is simply impossible to have enough of it without compromising either my revision or training time.

Carmen Lim, Swimming (S8)

1.2 THE SPORTS NUTRITION PATHWAY – FROM REHABILITATION TO HIGH PERFORMANCE

The spectrum of impairments can be subdivided into two main categories: those that are inborn or present at a very early age, and those that have been acquired. Individuals who have acquired their impairment, especially via trauma or from health-related issues such as cancer, will usually have undergone a period of rehabilitation which may have involved substantial time in hospital. An increasing number of Para athletes come from a military background, having acquired their impairment while on "active duty." Depending on the time frame between the onset of their impairment and entry into sport, the individual may also be having to deal with a wider range of practical and psychological issues, such as adjusting back to home, managing their impairment itself and its clinical manifestations, changing occupation, having to get carers to look after essential needs, etc. Information such as this should be asked early on as it assists in understanding the framework that the athlete is currently operating within.

Individuals who have acquired their impairment have likely been exposed at some point to nutrition education and support, since nutrition needs are elevated immediately post trauma for healing of wounds and at other times may have decreased substantially due to periods of inactivity. Indeed, there is a substantial range of scientific literature regarding many clinical aspects of impairments. There is a lot to be learnt from this literature, such as the nutritional management of pressure wounds, prevention of urinary tract infections and the understanding of bladder and bowel management for spinal cord injuries. However, it is also important to acknowledge the context of this work, which is generally embedded in acute post-injury/illness or long-term institutionalised practise. For example, studies of energy expenditure of, or body composition changes in, sedentary spinal cord injured (SCI) individuals may present results that are substantially different to the SCI athlete population; pressure wound management research is generally undertaken in bed-bound, potentially undernourished, individuals; and energy expenditure assessments in cerebral palsy have generally been undertaken in children whose activity levels are not reported.

Part of the challenge for a sports nutritionist working with Para athletes can be changing their mindset to what is required for high performance. This can be a substantial shift in nutrition focus in terms of volume, type and timing of food and fluid intake and, in fact, the whole reason for consuming food. It is not uncommon, particularly early in their involvement with sport, for energy requirements to be underestimated by the athlete, especially when weight control has been a focus and the individual was not an athlete prior to the injury/illness. Similarly, the deliberate restriction of fluid intake by a spinal cord–injured individual when travelling longer distances due to restrictions in accessing a bathroom needs addressing where health and the ability to perform on arrival is the priority. When changing an athlete's diet or hydration practises, it is important to explain why these changes may be beneficial, with the focus on optimising performance and health. It is also imperative to acknowledge and work within their own limitations and concerns, some examples of which are outlined in Table 1.1. Any dietary changes should be undertaken progressively, and the practitioner may require some patience to allow the process to evolve, especially where the athlete is having to manage a whole range of new scenarios. The outcomes will inevitably be worth it!

COMMENTARY BOX 1.2

COACH'S INSIGHT:

Our team has been working with our sports dietitian for the last 4 years, and her guidance has been instrumental in elevating our team's performance, from working with athletes to individualise their approach to nutrition, to finding ways for our team to support athletes to optimise performances. She has helped us identify and institute many small modifications to our daily routines that, when combined, have helped us continually improve in big ways.

Eileen Carey, High Performance Director (previously head coach), USA Para Nordic Ski team

TABLE 1.1
Challenges to Dietary Changes in Para Athletes

Nutritional Change	Limiting Factors	Para Athlete
Energy intake	Prosthesis fit	Lower limb amputees
	Transfer capability	Spinal cord injury, some forms of cerebral palsy
	Fit in racing/competition chair	Wheelchair athletes
Pre-exercise feeding	Body position during exercise	Wheelchair track athletes
Hydration	Access to clean bathroom facilities	Winter sport sit skiers
	Low sweat losses	Spinal cord injury or any athletes with neurogenic bladder
	Difficulty handling fluid containers during activity	Cerebral palsy/acquired brain injuries
		Upper body amputees
Fibre intake	Bowel management routines	Gastrointestinal motility issues
		Spinal cord injury
Food preparation (including purchasing)	Safety	Vision impairment, intellectual impairment
	Food choices	
	Accessible kitchens/supermarkets	Spinal cord injury, wheelchair users
	Swallowing difficulties	Cerebral palsy
		Upper and lower limb amputees
Clinical needs	Use of medications	All
	Sleep disturbances	
	Allergies/intolerances	
	Food aversions (taste/texture/smell)	

REFERENCES

International Paralympic Committee. 2017. IPC style guide. https://www.paralympic.org/sites/default/files/document/171212103704442_2017_03_03+IPC+Style+Guide.pdf

Maughan, R.J. and Burke, L.M. 2011. Sports nutrition: more than just calories—Triggers for adaptation. *Nestle Nutrition Institute Workshop Series*, vol. 69. Vevey: Nestec and Basel: S. Karger AG.

RECOMMENDED READING

McArdle, W.D., Katch, F.I. and Katch, V.L. 8th Edition. 2014. *Exercise Physiology; Nutrition, Energy and Human Performance*. Philadelphia: Lippincott Williams and Wilkins.

Vanlandewijck, Y.C. and Thompson, W.R. 2011. *The Paralympic Athlete*. West Sussex: Wiley-Blackwell.

2 Sport for Individuals with an Impairment

Peter Van de Vliet

CONTENTS

2.1 HISTORY OF SPORT FOR INDIVIDUALS WITH AN IMPAIRMENT

Sport for athletes with an impairment has existed for more than 100 years. In the eighteenth and nineteenth centuries, new contributions proved that sport activities were very important for the rehabilitation of injured persons. The first Sport Club for the Deaf was founded in Berlin in 1888, and the Comité International des Sports des Sourds (CISS, International Sports Federation for the Deaf) was founded in 1922 (Gold and Gold 2007). In 1924 the first International Silent Games were held. Amongst the earliest sports organisations for people with physical impairments were the Disabled Drivers Motor Club (1922) and the British Society of One-Armed Golfers (1932) (Brittain 2010).

Following World War II, traditional methods of rehabilitation could not meet the medical and psychological needs of large numbers of injured soldiers and civilians. At the request of the British government, Dr. Ludwig Guttmann, a Jewish medical doctor with specialty in neurology and neurosurgery who was forced to leave his post in a German hospital in war time, founded the National Spinal Cord Injuries Centre at the Stoke Mandeville Hospital in Great Britain in 1944. Guttmann introduced sport as a form of recreation and as an aid for remedial treatment and rehabilitation. Inspiration for incorporating sport in the rehabilitation program came from the patients themselves who had developed their own “active” programs.

On 28 July 1948 – the day of the Opening Ceremony of the Olympic Games in London – the Stoke Mandeville Games were founded, and the first competition for athletes with spinal cord injury took place on the hospital grounds in Stoke Mandeville, just 35 miles away from London. Two British teams with 14 former servicemen and 2 former servicewomen competed in archery. In the next year's edition, Dr. Guttmann, inspirer and organiser of the event, gave an opening remark in which he declared his hope that the Games would become international and achieve "world fame as the disabled men and women's equivalent of the Olympic Games" (Bailey 2007). In 1952, the event became "international" with the participation of ex-servicemen from The Netherlands. In 1960, the International Stoke Mandeville Games were staged for the first time in the same country and city as the Olympic Games, that is, in Rome. They went down in history as the "First Paralympic Games." The first Paralympic Winter Games took place in Örnsköldsvik in Sweden in 1976 (Bailey 2007; International Paralympic Committee 2006). From that early beginning, the "Movement" grew into a professional organisation, now known as the International Paralympic Committee (IPC), which is the global governing body of the Paralympic Movement, as well as the organiser of the Paralympic Summer and Winter Games. This event today involves 4200 athletes competing in 20 summer sports and 600 athletes in 5 winter sports. The historical growth is presented in Figure 2.1.

The word "Paralympic" was originally a pun combining "paraplegic" and "Olympic"; however, with the inclusion of other impairment groups at later stages and the closer association of the Paralympic Movement with the Olympic Movement, it now refers to "parallel" (from the Greek preposition "para") to the Olympic Games to illustrate how the two Movements exist side by side. "Paralympics" has been the official term of the Games since 1988 (Tweedy and Howe 2011). In the lead-up to the 1988 Games, the International Olympic Committee (IOC) agreed to the term "Paralympic" being used for the Seoul Games and all Games from then onward, and in 2001 the relationship between the IPC and the IOC was formalised in a detailed cooperative agreement (Bailey 2007).

Over the course of the first decades, rehabilitation remained an important driver for the development of Paralympic sport (Tweedy and Howe 2011), but little by little, sports participation started to grow beyond that stage, mainly by patients who had completed their hospital program and been discharged into the community. Their drive was no different from others in the community: to have enjoyment, social interaction, recreation, competition and enhanced health and well-being (Vallerand and Rousseau 2001).

2.2 THE PARALYMPIC MOVEMENT

Until 1952, the Stoke Mandeville Games were organised by Guttmann and his hospital staff, with a group of doctors, nurses, physiotherapists, trainers and administrators deciding on rules, classifications and all other factors. In 1961, the International Stoke Mandeville Games Committee was founded and took over responsibility for organising the Games until 1972 when the constitution was amended to form the International Stoke Mandeville Games Federation (ISMGF). In the 1990s, the ISMGF

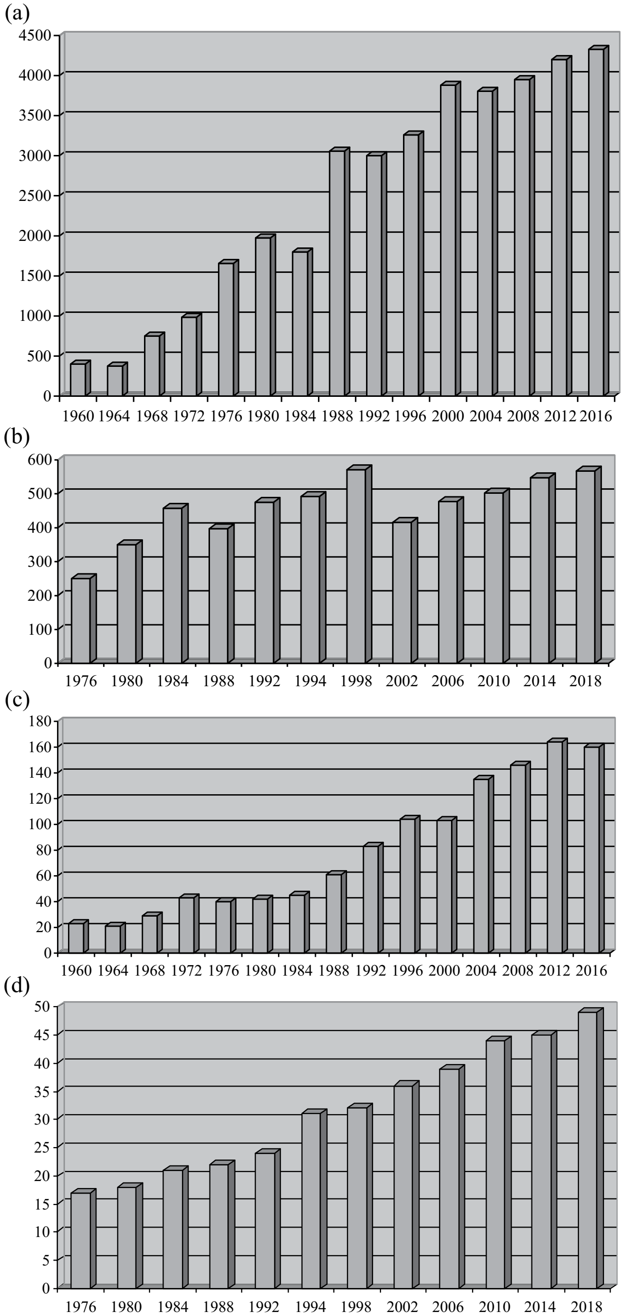


FIGURE 2.1 Growth of the Paralympic Movement. (a) Number of competitors at the Paralympic Summer Games; (b) number of competitors at the Paralympic Winter Games; (c) number of delegations at the Paralympic Summer Games; (d) number of delegations at the Paralympic Winter Games.

would become the International Stoke Mandeville Wheelchair Sports Federation (ISMWSF).

In the beginning, only athletes with a spinal cord injury participated in Paralympic sport, but through the 1970s and 1980s, the scope of the Movement expanded to also include athletes with other types of impairment, ultimately leading to the creation of an international umbrella organisation for Paralympic sport. This process was initiated in 1960, when an international "Working Group on Sport for the Disabled" was set up to study the challenges facing persons with an impairment who wanted to become involved in sport. Its aim was to establish an organisation that included all impairment groups. It resulted in the creation, in 1964, of an international sport organisation called ISOD: International Sport Organisation for the Disabled. ISOD offered opportunities for those athletes who could not belong to the ISMGF, including athletes with vision impairment, amputation and cerebral palsy. ISOD achieved their inclusion in the Toronto 1976 Paralympic Games (athletes with vision impairment and amputation) and in the Arnhem 1980 Paralympic Games (athletes with cerebral palsy).

From these initial structures, different impairment groups established their own international sports organisations that arranged various competitions, ultimately leading to today's International Organisations of Sport for the Disabled:

- CPISRA: Cerebral Palsy International Sport and Recreation Association
- IBSA: International Blind Sports Federation
- INAS: International Federation for Athletes with Intellectual Impairments (previously named INAS-FID)
- IWAS: International Wheelchair and Amputee Sports Federation (amalgamation of ISOD and ISMWSF in 2004)
- CISS: Comité International des Sports des Sourds (member of the Paralympic Movement from 1986 to 1995)

These international organisations recognised the need to coordinate both the Paralympic Games and other international and regional sports competitions. Therefore, ISOD, ISMGF, CPISRA and IBSA created the "International Coordination Committee of World Sports Organisations for the Disabled (ICC)" in 1982 to govern the Paralympic Games and to represent the participating organisations in dialogues with the IOC and other global organisations (Bailey 2007). This need for a united voice in negotiations with organising committees reflected Dr. Guttmann's philosophy that an attempt should be made to organise the "Paralympic Games" back to back with the Olympic Games.

The member nations demanded more national and regional representation in the ICC, and this finally led to the foundation in 1989 of a new, democratically organised institution: the "International Paralympic Committee." Initially headquartered in Bruges, Belgium, the organisation moved to Bonn, Germany, in 1999, and with that move, professional management team structures were introduced. Currently the Olympic and Paralympic Movements have become so closely aligned that it is reasonable to posit that Dr. Guttmann's 1948 vision – that the Paralympic Games would become the "disabled men and women's equivalent of the Olympic Games" – has been realised (Tweedy and Howe 2011).

COMMENTARY BOX 2.1

COACH'S INSIGHT: What do you believe are the biggest differences in coaching athletes with an impairment compared to able-bodied athletes? For example, what modifications do you have to make to your training programs and/or coaching style? Does this differ between different impairments?

> I think this is truly dependent on the individual, an n = 1 scenario. My overall coaching philosophy may remain constant. However, you must remain creative and adaptable in order to problem solve and find applicable best practises. Working with Para athletes enables me to be challenged on a daily basis with the mission of finding new ways to enable this sporting population to reach new levels of peak performance.

Sam Gardner, US Paralympics Strength & Conditioning Coach

2.3 PARALYMPIC SPORTS

The Paralympic Games represent an international, multisport competition for athletes with an impairment that reflects the highest standards of athletic excellence and diversity. The goal of the Paralympic Sports Program is to provide exciting and inspiring events in the Paralympic Games that allow athletes to achieve competitive excellence while engaging and entertaining spectators.

The IPC conducts a quadrennial review of which sports, disciplines and medal events are included in the Paralympic Games. Each sport and discipline applying for inclusion must meet specific minimum eligibility conditions and must have a level of organisational infrastructure and professionalism that is sufficient to manage and sustain their sport. The main conditions are:

- The Sport is governed by an International Federation which is a member of the Paralympic Movement. Criteria for membership are explicit in the IPC Handbook (www.paralympic.org). This governing body can be the IPC itself, an International Federation governing an Olympic Sport, an International Sport Organisation for the Disabled or an International Sport Federation specifically for athletes with an impairment. An overview of sports governance (2018) is presented in Table 2.1.
- The Sport is organised for athletes with an impairment, with wide and regular practise across nations and regions. For individual sports: a minimum of 32 nations in 3 regions (Summer Games), a minimum of 12 nations in 3 regions (Winter Games). For team sports: a minimum of 24 nations in 3 regions (Summer Games), a minimum of 8 nations in 3 regions (Winter Games).
- Statutes, practises and activities are in conformity with the IPC Handbook and contribute to the IPC Vision and Mission, including the adoption and implementation of Codes and guidelines of fair play (including Anti-Doping Code, Classification Code, Medical Code, Code of Ethics).

TABLE 2.1
Governing Bodies of Sports on the Paralympic (Winter) Games Program for PyeongChang 2018 and Tokyo 2020 (Governance Status as of June 2018)

Sport	International Federation	Impairment Types
Alpine Skiing[a]	International Paralympic Committee (IPC)	P/V
Archery	World Archery (WA)	P
Athletics	International Paralympic Committee (IPC)	P/V/I
Badminton[b]	Badminton World Federation (BSF)	P
Boccia	Boccia International Sports Federation (BISFed)	P
Canoe	International Canoe Federation (ICF)	P
Cycling	Union Cycliste Internationale (UCI)	P/V
Equestrian	Fédération Internationale d'Equitage (FEI)	P/V
Football 5-a-side	International Blind Sport Federation (IBSA)	V
Goalball	International Blind Sport Federation (IBSA)	V
Para Ice Hockey[a]	International Paralympic Committee (IPC)	P
Judo	International Blind Sport Federation (IBSA)	V
Nordic Skiing[a] (cross-country + biathlon)	International Paralympic Committee (IPC)	P/V
Powerlifting	International Paralympic Committee (IPC)	P
Rowing	International Rowing Federation (FISA)	P/V
Shooting	International Paralympic Committee (IPC)	P
Snowboard[a]	International Paralympic Committee (IPC)	P
Swimming	International Paralympic Committee (IPC)	P/V/I
Table Tennis	International Table Tennis Federation (ITTF)	P/I
Taekwondo[b]	World Taekwondo (WT)	P
Triathlon	International Triathlon Federation (ITF)	P/V
Volleyball (Sitting)	World Paravolley (WPV)	P
Wheelchair Basketball	International Wheelchair Basketball Federation (IWBF)	P
Wheelchair Curling[a]	World Curling Federation (WCF)	P
Wheelchair Fencing	International Wheelchair and Amputee Sports (IWAS)	P
Wheelchair Rugby	International Wheelchair Rugby Federation (IWRF)	P
Wheelchair Tennis	International Tennis Federation (ITF)	P

Abbreviations: P, including athletes with physical impairment: V, including athletes with vision impairment; I, including athletes with intellectual impairment (note: all athletes must meet eligibility and classification criteria as defined by the sport).

[a] Winter Games program.

[b] New sport in the Tokyo 2020 Paralympic Games program.

- The Sport has a structure of national organisations each recognised by its own country.
- The Sport can demonstrate a regular quadrennial competition program including two world championships over the last eight years.
- The Sport has a sustainable governance and organisation structure that effectively manages the sport.

The final decision on the Paralympic Games sports program lies with the IPC Governing Board and is based on the assessment of three core characteristics which broadly outline the philosophical priorities of the Paralympic program within the boundaries of the overarching IPC–IOC agreement (defining maximum number of sports and athletes). These characteristics are presented in Table 2.2.

The sport-technical rules of Paralympic sports are tailored – where needed and appropriate – to the needs and demands of the athletes competing in the sport. A systematic overview of all modifications falls outside the scope of this chapter, but examples include:

- Two-bounces of the ball in wheelchair tennis before returning
- Guide runners connected to athletes with vision impairment via tethers
- Skiing guides using sound systems to assist skiers with vision impairment
- Use of technical aids to steer horses
- Ball-bouncing rules in wheelchair basketball
- Use of soft springs in pistol shooting, use of supportive devices to hold rifles

When sports do not have an Olympic or able-bodied equivalent, as is the case with Goalball and Boccia, for example, the sport's governing body has developed its own set of sport-technical rules. For a full and comprehensive overview, the reader is referred to the sport-technical rules of each sport on the IPC website (http://www.paralympic.org/Sports).

The introduction and continued development of Paralympic-specific equipment has been part of the evolution of the Paralympic Movement. Since standard devices could inhibit sporting performance or create a safety issue, sport-specific wheelchairs and prostheses, modifications to sailing and rowing equipment and the design of sport-specific equipment such as sledges (Para ice hockey) or sitskis (Alpine/Nordic Skiing) have been developed. The sporting bodies have a responsibility to consider equipment matters in a holistic approach (Burkett 2010), striving to ensure progress in technological developments goes hand in hand with an even playing field that ensures safe sport participation and equity of access to technology-driven equipment. Consequently, the Paralympic Movement has developed an "IPC Equipment policy" which all sports are required to implement (International Paralympic Committee 2011).

2.4 CLASSIFICATION

Efforts to promote Paralympic sports as elite must be clear about what elite performance is in the Paralympic context, and "classification" is a critical component

TABLE 2.2
General Rules and Principles for Participation in the Paralympic Games

Eligibility Code compliance	Every competitor, team official and Games official shall: • Respect the spirit of fair play and nonviolence and behave accordingly. • Respect and comply with all the procedures and policies outlined in the IPC Classification Code and IPC Anti-Doping Code, while co-operating on these issues with the authorised officials. • Refrain from advertising during the Paralympic Games with his/her person, name, picture or sports performance. • Not accept any payment or other material gain or consideration for participation in the Paralympic Games. • Not allow commercial exploitation of his/her image, name and/or performance without prior approval from IPC. • Abide by rules and regulations related to clothing and equipment. • Accept sport technical supreme authority of the respective IF and of IPC.
Discrimination and propaganda	No discrimination is allowed on political, religious, economic, disability, racial, gender or sexual orientation or any other grounds against any country or individual.
Nationality of participants	A competitor in the Paralympic Games must comply with the terms and policies outlined in the athlete nationality policy of the IPC Handbook in order to represent a National Paralympic Committee.
Anti-Doping Code	Compliance to the World Anti-Doping Code and the IPC Anti-Doping Code is mandatory for the whole Paralympic Movement.
Classification Code	Compliance with the IPC Classification Code is mandatory for all participants in the Paralympic Games.
Commercial advertising	Athletes, team officials and other constituents participating in the Paralympic Games shall refrain from commercial activities that negatively affect the image of the Paralympic Games or the Paralympic Movement.
Disciplinary measures	Disciplinary measures may be taken against any athlete or any team member who: • Contravenes the spirit of fair play. • Manifestly offends member of any IPC board or committee, officials, referees or members of the OCOG in the course of his/her official duties. • Behaves himself/herself in a manner which discredits IPC or the organisers. • Acts or behaves in a way that is considered unethical by the IPC Legal and Ethics Committee.
Dispute arbitration	All disputes related to sports technical rules arising during the Paralympic Games are under the authority of the respective IF and IPC, as set out in the sports technical rules and the IPC Handbook, and (where not otherwise resolved) will be resolved by IPC, whose decision on these matters is final, nonappealable and enforceable.

Source: Extracted from International Paralympic Committee. 2017. *Paralympic Games Chapter*. http://www.paralympic.org – The IPC – IPC Handbook (accessed June 21, 2018), Section 1, Chapter 3.

Abbreviations: IPC, International Paralympic Committee; IF, International Federation; OCOG, Organising Committee of the Olympic Games.

of Paralympic sports. Hence, understanding Paralympic sports requires a minimal introduction to classification.

Different forms of classification exist in sport, examples including events by gender, weight category or age (youth series, master classes). Grading systems to organise competition (e.g., soccer leagues) are also classification systems. The Paralympic Movement provides competitive sporting opportunities for athletes with a range of impairments and, as such, interrelates a concept of "health and conditioning" with "sport" (Tweedy and Vanlandewijck 2011). This relationship constitutes the basis of Paralympic classification.

2.4.1 Historical Perspective

A first reference to classification can be found in Joan Scruton's biography on the origins of the Paralympic Movement when conclusions were drawn from the 1955 International Stoke Mandeville Games: "consideration must be given to whether it would not be fairer to divide the netball competition into at least two classes – higher and lower lesions" (Scruton 1998, p. 77). The outcome of the discussion was a change from netball to wheelchair basketball with a division of the competition into two classes: (a) for complete spinal cord lesions and (b) for incomplete spinal cord lesions (Scruton 1998). From that moment onwards, the incorporation of sports in rehabilitation programs came with the development of impairment-based systems of classification. Athletes started to receive a single "class" based on their medical diagnosis and competed in that class for all sports. This basis of classification meant that impairments resulting from different medical conditions (e.g., spinal cord injury resulting in lower limb paralysis versus double above-knee amputation) yet resulting in roughly the same activity limitation in wheelchair propulsion were not considered in the classification process (Tweedy and Vanlandewijck 2011). As the Paralympic Movement matured and turned into a sport-driven organisation over a medical system extending from rehabilitation, "functional" classification systems began to be implemented. Initial efforts hereto date from the late 1970s and the 1980s. In functional systems, the main factors that determine class are not diagnosis and medical evaluation, but how much the impairment of a person impacts sports performance. Consequently, functional classification systems are sport-specific (Tweedy and Howe 2011) because any given impairment may have a significant impact in one sport yet a relatively minor impact in another.

2.4.2 Current Paralympic Classification

As an outcome of this historical development and with the growth of the Movement, every sport ended up with its own system of classification, primarily based on expert opinion provided by "classifiers" with a diverse range of backgrounds – medical doctors, therapists, athletes and coaches. While the majority share the above key features there is considerable variability on a range of fundamental issues, including the definition of key terms and the basis for determining minimum impairment criteria. Sherrill (1999) and Tweedy (2002) pointed in particular at the absence of a theoretical or conceptual model to guide Paralympic classification.

The IPC has recognised the need to coordinate classification under these provisions, and in 2003 the IPC conducted a classification audit, which recommended the development of a universal Classification Code "to support and co-ordinate the development and implementation of accurate, reliable and consistent sport focused classification systems" (International Paralympic Committee 2007).

The IPC Classification Code got approved by the IPC General Assembly in 2007 (International Paralympic Committee, 2007). In 2015, the IPC published a revised IPC Athlete Classification Code, again following extensive consultation with its stakeholders (International Paralympic Committee, 2015). Article 2 of the Code details the definition and purpose of classification in Para-sport. Given their importance, article 2 is quoted here in its entirety:

> 2.1 Athlete Classification in the Paralympic Movement (referred to in the Code as "Classification") is a defining feature of Para-sport. It is defined as grouping Athletes into Sport Classes according to how much their Impairment affects fundamental activities in each specific sport or discipline.
>
> 2.2 The purpose of Classification is to define who competes in Para-sport and to ensure that the impact of Eligible Impairment in each event is minimised. To achieve this purpose, each International Federation (IF) must develop and implement a Classification System that complies with the Code and International Standards. Specifically, a Classification System must:
>
> 2.2.1 clearly state that an Athlete must have an Eligible Impairment in order to compete in the sport. Such Impairments must come from the list of Eligible Impairments presented in the International Standard for Eligible Impairments.
>
> 2.2.2 Set processes and procedures for assessing whether an Athlete has an Eligible Impairment. These processes and procedures must conform with the International Standard for Eligible Impairments.
>
> 2.2.3 Set Minimum Impairment Criteria for each Eligible Impairment. Minimum Impairment Criteria must be written in a way that can be objectively assessed and comply with the International Standard for Eligible Impairments and for Athlete Evaluation.
>
> 2.2.4 Require that Athletes are allocated a Sport Class based on the extent to which Athletes are able to execute the specific tasks and activities fundamental to the Para-sport or discipline. This process by which Sport Classes are allocated must comply with the International Standard for Athlete Evaluation.

The International Standards, detailing the technical and operational requirements for classification, further expand on this article. It can best be summarised as follows:

- Step 1 in the classification process is to identify if an athlete holds an eligible impairment for a certain sport. The Paralympic Movement offers sport opportunities for athletes with physical, vision and intellectual impairments, and these can be divided into 10 eligible impairment types (impaired muscle power, impaired passive range of movement, limb deficiency, leg length difference, short stature, hypertonia, ataxis, athetosis, vision impairment, intellectual impairment; International Paralympic Committee 2015). Each sport decides which impairment type(s) its sport will cater to. Some sports are only designed for athletes with one impairment type. Goalball, for example, is only open for athletes with vision impairment. Other sports, such as Athletics and Swimming, are open to athletes in any of the 10 impairment types. Athletes will need to submit medical diagnostic information to prove the existence of an eligible impairment type.

- Step 2 is to decide how severe an impairment has to be in order for an athlete to be eligible to compete in their sport (so-called Minimum Impairment Criteria). This severity is identified by the impact on the sport performance as explained above. The process of classification involves a physical (medical) assessment and a technical (sport-specific) assessment, done by classifiers, sometimes also complemented by observation in training and/or competition. Classifiers are specialists trained and certified by the International Federation that governs the sport. Their profile is different depending the impairment types they assess (e.g., [Para-]medical background and/or technical expertise in a sport for athletes with physical impairment, ophthalmologist or optometrist for athletes with vision impairment, and psychologists and/or technical expertise in a sport for athletes with intellectual impairment). It is crucial to understand that the presence of an eligible impairment is a prerequisite but not an inclusive criterion. Inclusion only is a fact when the severity of the impairment impacts the sport performance (a so-called minimal impairment).
- Step 3 is the allocation of a sport class to group athletes together depending on how much their impairment impacts performance in a particular sport. Although there is no common standard to identify sport classes, classification systems can more or less be categorised in three groups:

  - "open classes": all athletes competing only need to meet the minimal impairment criterion;
  - "letter-number combinations": most sports have a letter code (referring to sport or discipline, e.g., S in Swimming stands for freestyle, backstroke and butterfly, and SB stands for breast stroke; T in Athletics stands for running/wheelchair racing and jumping, and F stands for throwing events).
  - "point scores": typically in use in team sports, athletes are given a point score with lower points indicating more severe activity limitations. A maximum number of points is allowed on the field of play at any given time, ensuring a spread of athletes competing with diverse activity limitation.

The description of classification details in each Para-sport goes far beyond the capacity of this single chapter. The reader is referred to the IPC website to retrieve further details about the sport-specific classification rules of each sport (see http://www.paralympic.org/Classification/Introduction).

2.4.3 Towards Sport-Specific Evidence-Based Classification in Para-Sport

All systems of classification in Para-sport in future need to be based on the Code provision to promote participation in sport by people with impairments by minimising the impact of eligible impairment types of the outcome of competition. This requires all classification systems to describe eligibility criteria ("who is in?") in terms of type and severity of impairment, and to describe methods for classifying eligible impairment according to the extent of activity limitation they cause in a particular sport or sports discipline.

The IPC firmly believes in the value of scientific research to assist this process, and has embedded this in the Code (article 10.2 – IFs must develop sport-specific classification systems through multidisciplinary research). Tweedy and Vanlandewijck (2011) outline the principles that should be upheld when initiating such research, and the IPC has endorsed their publication as official IPC position stand on classification in Paralympic sport. Subsequent publications expand on the principles outlined in the 2011 publication (Tweedy and Howe 2011; Tweedy et al. 2014, 2016), and most recently both the IPC and International Blind Sports Federation (IBSA) adopted a position stand on sport-specific classification for athletes with vision impairment (Mann and Ravensbergen 2018). The authors acknowledge that classification in Paralympic sport is a complex and dynamic process, and they point at some key features that strengthen sound classification systems. These include:

- Measurement of impairment should be secured by means of simple, readily available, objective tests that account for the greatest variance in sports performance.
- Measurements must prioritise key components of the sport.
- Insight should be gained in training history and personal and environmental factors affecting how well an athlete will do the activity. A crucial and critical aspect of Paralympic classification is that enhancement in performance through training may NOT lead to class changes.
- Development of detective tools to identify intentional misrepresentation of abilities. It is inherent to the human being and thus athletes to try to obtain favourable outcomes of testing, and anecdotal evidence suggests that athletes may not cooperate fully during testing or attempt to exaggerate the severity of their impairment.

The development of evidence-based classification systems implies the engagement of individuals who know the sport (administrators, officials – including classifiers – as well as athletes) and sports scientists, whether or not they are currently working with Paralympic athletes. More recently, this has driven the instigation of expert meetings in which academics experienced in assessing impairment and sports scientists involved in the development of able-bodied equivalents of Paralympic sports have been brought together with experts in Paralympic sports. The complementary expertise, knowledge and resources of these key players ensure that further development of Paralympic classification systems will focus on the development of objective, reliable methods for measuring both of the core constructs in the model: impairment and activity limitation. The Code requires that athlete input must be solicited throughout this process.

The above is all indicative of the dynamic, though complex, matter of Paralympic classification so that ultimately the success of an athlete is determined by skill, fitness, power, endurance, tactical ability and mental focus, no different to any able-bodied counterpart.

Over the past years, multiple research initiatives based on the above theoretical or conceptual model have been launched in different sports.

COMMENTARY BOX 2.2

ATHLETE INSIGHT: What sports nutrition practises have had the biggest impact on your training capability or performance?

> The idea of adding little things to my nutritional training each year is what has helped me the most. Most of us Paralympic athletes don't compete full time, so learning ways to weave in the information you are taught into our everyday lives, little by little, is key. When I was young I used to roll my eyes during nutrition presentations thinking, "I know all of this." Now, because of my nutritional foundation, I've been able to compete at a high level for more than 10 years and I'm constantly learning new things each year.

Steve Serio, Wheelchair Basketball, three-time Paralympian (Beijing, London – Bronze medal and Rio – Gold medal)

2.5 CONCLUSION

From its origin in the 1940s, the Paralympic Movement has undergone multiple changes with a shift from disability-centred structures to sport-specific ethos. This advancement was greatly enhanced by sustained affirmative assistance from the IOC, and the development of criteria for sustainable Paralympic sports which set standards to ensure both further growth and sporting excellence. With the growth of the Paralympic Movement, the concept of classification has undergone a shift. From an initial medical model, the Paralympic Movement has developed a conceptual model of sport-specific evidence-based classification, which is founded in the IPC Athlete Classification Code. All sports in the Paralympic Movement have now signed up to this process, in an initial phase by a critical self-audit of their current classification system, a consultative journey with the IPC and through the engagement of sport scientists from different disciplines in the review and further development of classification. The outcome is a continued critical reflection on how classification – the cornerstone of the Paralympic Movement – can be improved to ensure that the athlete with the best sportive skills, independent from his or her impairment, ultimately is the one that wins.

REFERENCES

Bailey, S. 2007. *Athlete First. A History of the Paralympic Movement*. Hoboken: John Wiley & Sons Inc.

Brittain, I. 2010. *The Paralympic Games Explained*. Abingdon: Routledge.

Burkett, B. 2010. Technology in Paralympic Sport: Performance enhancement or essential for performance? *British Journal of Sports Medicine* 44:215–220.

Gold, J.R. and Gold, M.M. 2007. Access for all: The rise of the Paralympic Games. *The Journal of the Royal Society for the Promotion of Health* 127:133–141.

International Paralympic Committee. 2006. *Paralympic Winter Games 1976–2006*. Bonn: International Paralympic Committee.

International Paralympic Committee. 2007. *IPC Classification Code and Standards*. http://www.paralympic.org – The IPC – IPC Handbook (accessed June 21, 2018).

International Paralympic Committee. 2011. *IPC Equipment Policy*. http://www.paralympic.org – The IPC – IPC Handbook (accessed June 21, 2018).

International Paralympic Committee. 2015. *IPC Athlete Classification Code and Standards*. http://www.paralympic.org – The IPC – IPC Handbook (accessed June 21, 2018).

International Paralympic Committee. 2017. *Paralympic Games Chapter*. http://www.paralympic.org – The IPC – IPC Handbook (accessed June 21, 2018).

Mann, D.L. and Ravensbergen, H.J.C. 2018. International Paralympic Committee (IPC) and International Blind Sports Federation (IBSA) joint position stand on the sport-specific classification of athletes with vision impairment. *Sports Medicine*. doi: 10.1007/s40279-018-0949-6. [Epub ahead of print].

Scruton, J. 1998. *Stoke Mandeville: Road to the Paralympics*. Aylesbury: The Peterhouse Press.

Sherrill, C. 1999. Disability sport and classification theory: A new era. *Adapted Physical Activity Quarterly* 16:206–215.

Tweedy, S.M. 2002. Taxonomy theory and the ICF: Foundations for a unified disability athletics classification. *Adapted Physical Activity Quarterly* 19:220–237.

Tweedy, S.M. and Howe, P.D. 2011. Introduction to the Paralympic Movement. In *The Paralympic Athlete*, eds. Vanlandewijck, Y.C. and Thompson, W.R. pp. 3–30. Hoboken: Wiley-Blackwell.

Tweedy, S.M. and Vanlandewijck, Y.C. 2011. International Paralympic Committee Position Stand – Background and scientific rationale for classification in Paralympic sport. *British Journal of Sports Medicine* 45:259–269.

Tweedy, S.M., Beckman, E. and Connick, M.J. 2014. Paralympic classification: Conceptual basis, current methods and research update. *Physical Medicine and Rehabilitation* 6:S11–S17.

Tweedy, S.M., Mann, D. and Vanlandewijck, Y.C. 2016. Research needs for the development of evidence-based systems of classification for physical, vision and intellectual impairments. In *Training and Coaching the Paralympic Athlete*, eds. Vanlandewijck, Y.C. and Thompson, W.R. pp. 122–149. Chichester: John Wiley & Sons, Ltd.

Vallerand, R.J. and Rousseau, F.L. 2001. Intrinsic and extrinsic motivation in sport and exercise. In *Handbook of Sport Psychology*, 2nd edition, eds. Singer, R.N., Hausenblaus, H.A. and Janelle, C.M. pp. 389–416. New York: John Wiley & Sons Inc.

3 Principles of Sports Nutrition

Elizabeth Broad and Louise M. Burke

CONTENTS

3.1 INTRODUCTION

The principles of sports nutrition have evolved substantially over the past three decades, whereby present day recommendations are individualised to the athlete's specific performance-related goals and periodised according to the time of the week, macrocycle and stage of athlete's development and sporting career. The core goals are to promote consistency of training, maximise adaptations to training which result in metabolic flexibility and efficiency, and then optimise performance on the day of competition. These outcomes are underpinned by the need to achieve appropriate body composition, promote health and well-being, minimise the time lost to illness and injury and maintain the enjoyment of food. Sports nutrition principles can be applied across the spectrum of athletic endeavour, from the developmental athlete through to the "elite" performer, as well as the individual who exercises for general fitness and weight control.

The aim of this chapter is to "set the scene" for sports nutrition guidelines, from which other chapters in this book can draw. Since there are very few scientific studies specifically undertaken on athletes with an impairment, this chapter will outline the guidelines developed for able-bodied athletes and highlight areas that may need adapting for athletes with an impairment. Subsequent chapters will further explore the reasons why adaptations may be necessary and outline solutions. The process of developing individualised periodised approaches from general guidelines is no different for athletes with an impairment than it is for able-bodied athletes. Practitioners should aim to develop a sound knowledge of the events in which their athletes compete so that the specific physiological requirements, practical challenges and culture of the sport can be appreciated and integrated into the sports nutrition plan. Finally, the plan must be fine-tuned to the individual through practise and feedback.

In undertaking this review, we will assume readers have a pre-existing understanding of basic exercise physiology, exercise biochemistry and nutrition. We will aim to cover a range of contemporary issues of sports nutrition, including a focus on principles that have been recently updated or have become a source of debate. Readers are advised to seek more detailed information from the recommended reading material provided in the reference list.

3.2 GOALS OF TRAINING NUTRITION

3.2.1 Achieving Optimal Energy Availability for Training Support and Health

An athlete's energy intake underpins their nutritional status by establishing their capacity to consume macronutrients (including carbohydrate, protein and essential fatty acids) and by influencing their micronutrient intakes in conjunction with the nutrient density of their food choices. It provides support for the many processes needed for optimal performance, health and body function as well as allowing the manipulation of physique in conjunction with the training stimulus. Over the past decade, there has been increasing awareness of the separate issues of energy balance (the match between an athlete's energy intake and energy expenditure, modulated principally through changes in training load) and energy availability (the energy left over to support body processes when the energy cost of training is subtracted from an athlete's energy intake). This awareness extends both to the challenges of calculating the components of energy balance and energy availability as well as the impairments of health and performance associated with poor management of these issues.

3.2.1.1 Resting Energy Expenditure

Assessing an athlete's diet for nutritional adequacy will require, at some point, an assessment or estimation of daily energy requirements. Assessing energy balance is also important when there is a desire to change body composition, or where the athlete is suffering from fatigue, frequent illness, failure to grow at an appropriate rate or other factors which can be linked to an energy imbalance or low energy availability.

Estimating the energy expenditure of athletes can be a complex task, even if you have tools by which you can measure some of the individual components – resting or basal metabolic rate (RMR), thermic effect of feeding (TEF) and thermic effect of activity (both planned exercise and non-sport related, TEA). Since measuring energy expenditure requires either expensive techniques (e.g. doubly labelled water) or specialised equipment (indirect calorimetry), the practitioner generally relies on established prediction equations to estimate RMR, then multiplies RMR by an appropriate activity factor to estimate total energy expenditure. Thompson and Manore (1996) determined that the prediction equations which best matched measured RMR for active males and females were the Cunningham (1980) equation if a measure of lean body mass (LBM) is available, or the Harris Benedict equation (Harris and Benedict 1919) when LBM cannot be directly measured, which is supported by the American College of Sports Medicine (Thomas et al. 2016). Howell et al. (2015) showed that prediction equations using absolute body weight (including Harris Benedict) either over- or underestimated RMR in over 75% of individuals with traumatic limb loss, with differences between estimated and measured RMR ranging from −1285 to +2218 kJ/day (−306 to +528 kcal/day). They concluded that a simple equation of 105 kJ (25 kcal)/kg body weight was the best predictor of RMR in these individuals with limb loss as well as an able-bodied control group (Howell et al. 2015). These equations were derived from free living, able-bodied, nonathletes, hence their applicability to athletes, individuals with substantial muscle atrophy or missing limbs, those with regular muscle spasm and individuals whose body morphology (e.g. height and body mass) lies below the 5th or above the 95th percentile for age is uncertain.

Several recent studies in individuals with spinal cord injuries (SCIs) and Para athletes have provided some further evidence to support the use of an equation using LBM. Chun et al. (2017) developed a SCI-specific equation based on 50 (38 males, 12 females) nonathlete, motor complete SCI, free living subjects. The group included 27 quadriplegics and 23 paraplegics. The limits of agreement with the newly developed prediction equation ranged from 962 to 1012 kJ/day (229 to 241 kcal/day), and were similar in magnitude to an already existing prediction equation based on non-SCI individuals, which led the authors to conclude there is a considerable bias in estimating individual RMR from prediction equations regardless of the population they're derived from (Chun et al. 2017). This data was supported by Nightingale and Gorgey (2018) in males with motor complete SCI. In studies undertaken on Para athletes, Pelly et al. (2018) reported that the Cunningham equation best predicted measured RMR in five male athletes with SCI. In Brazilian track and field athletes, the Owen equation (Owen et al. 1987) was found to predict RMR most accurately in athletes with cerebral palsy or a minor limb deficiency, while the Mifflin equation (Mifflin et al. 1990) was more accurate for athletes with vision impairments (Juzwiak et al. 2016). Finally, Owen, Cunningham, Chun and Mifflin equations were all found to be excellent predictors of RMR in wheelchair rugby players (Broad et al. in review). Like the Cunningham equation, Mifflin, Chun and Owen all use LBM. All of these researchers found the Harris Benedict equation to be less accurate in predicting RMR, with inconsistencies as to whether it under- or overpredicted. Therefore, if the accurate assessment of LBM is possible in Para athletes (as outlined in Chapter 13), then it is recommended that either Cunningham or Owen equations be used to predict RMR. In other instances, the Harris Benedict equation can be used provided the practitioner allows for lower accuracy of the estimate, using the information gained in conjunction with other parameters such as current dietary intake, body composition change and ability to complete all training in order to provide information back to the athlete. Table 3.1 presents the different equations. In order to simplify the use of different terms across studies, LBM is used instead of fat free mass and RMR instead of basal metabolic rate or resting energy expenditure, acknowledging that there may be small differences between them.

3.2.1.2 Energy Expenditure of Exercise and Total Daily Energy Requirements

Once RMR has been estimated, an activity factor (or factors) must then be applied to estimate total daily energy expenditure. Often, a single activity factor is selected (e.g. 1.2 for bed rest or 1.5 for moderate exercise 3–5 days/week) and the RMR multiplied by this activity factor. The difficulty generally lies in determining how best to measure or estimate the energy expenditure of planned exercise. Separating out activities over a day and estimating expenditure within each component, from a compendium of exercise or similar (Ainsworth et al. 2011, Collins et al. 2010, Conger and Bassett 2011), is time consuming and relies on many assumptions. While having more impairment-specific data is useful, the majority of studies on athletes with SCI involve very small numbers and sometimes a combination of males and females, which limits their applicability on an individual basis. Furthermore, if the data compiled uses studies from over 10 years ago, technological and training advances in Para sports may have altered the results. For example, Conger and Bassett (2011) state the energy expenditure of wheelchair racing to be 33.2 kJ/kg/h (7.9 kcal/kg/h), whereas a recent report of elite wheelchair racing athletes over a 25-km time trial on the road produced values of 45.4–47.5 kJ/kg/h (10.8–11.3 kcal/kg/h) for males and 30.7–43.3 kJ/kg/h (7.3–10.3 kcal/kg/h) for females (Edwards et al. 2018). The availability of energy expenditure data for the wider range of Para athletes and sports is substantially lacking.

TABLE 3.1
Equations to Estimate Resting Metabolic Rate

References	Equation for RMR (kcal/d)	Reference Population
Cunningham (1980)	RMR = 500 + [22 × LBM]	120 male and 103 female nonathlete adults from Harris & Benedict study
Owen et al. (1986, 1987)	Males: RMR = 290 + [22.3 × LBM] Females: RMR = 50.4 + [21.1 × Wt]	60 healthy lean and obese males aged 18–82 years 44 healthy lean and obese females (8 athletes) aged 18–65 years
Chun et al. (2017)	RMR = [24.5 × LBM] + 244.4	50 adults (38 males, 12 females) with motor complete paraplegia or quadriplegia, nonathletes
Nightingale and Gorgey (2018)	RMR = [23.469 × LBM] + 294.330	30 male motor complete paraplegia and quadriplegia, nonathletes
Mifflin (1990)	RMR = [19.7 × LBM] + 413 RMR = [10 × Wt] + [6.25 × Ht] − [5 × age] + [166 × (1 for males, 0 for females)] − 161	251 males and 247 females who were both normal and obese aged 19–78 years
Harris and Benedict (1919)	Males: RMR = 66.47 + [13.75 × Wt] + [5 × Ht] − [6.76 × age] Females: RMR = 655.1 + [9.56 × Wt] + [1.85 × Ht] − [4.68 × age]	136 males and 103 females, healthy normal weight

Note: Since all RMR is in kcal/d, multiply by 4.2 to reach kJ/day.
Abbreviations: RMR, resting metabolic rate; LBM, lean body mass in kg; Ht, height in cm; Wt, weight in kg; Age, age in years.

Recent technology has produced tools which may simplify the process, including equipment that can directly measure power output during exercise and activity monitors that incorporate combinations of heart rate, step counts, movement patterns and body temperature changes. These tools can be variable at estimating true energy expenditure of activity and total daily energy expenditure, with greater accuracy at relatively low energy expenditures compared to high (Chowdhury et al. 2017). Predictive capacity in wheelchair users is generally lower due to altered movement patterns and variations in metabolically active tissues (Nightingale et al. 2017). Furthermore, in sports or activities with a complex range of movements, such as in stop-start sports with changes in direction, abnormal gait mechanics, high intensity exercise or where muscle spasm is regularly occurring, the more difficult it becomes to accurately assess energy expenditure of activity. While significant improvements are being made in technology with multisensor devices, more work is needed, especially for athletes. Nightingale et al. (2017) present an excellent summary to date on methods to assess activity energy expenditure in wheelchair users.

Since no single tool is without measurement error (on the order of 5%–30%; Chowdhury et al. 2017, Nightingale et al. 2017, Shephard and Aoyagi 2012), the outcome is inevitably going to be an approximation which should be interpreted accordingly. Similarly, assessment of true energy intake in free living individuals is complex, with under-reporting being a common problem (Deakin et al. 2015). There are very few publications on the dietary intakes of Para athletes, and most of them are in SCI or wheelchair athletes and did not assess energy expenditure at the same time. In the only study which has reported both, 17 male and female Para track and field athletes who had a vision impairment (n = 10), cerebral palsy (n = 4) or a limb deficiency of <10% of total body content (n = 3) underwent a 4-day assessment where their dietary intake was recorded at a testing camp by an external observer using photographs (Joaquim et al. 2018). Their mean energy intakes were 9500–10,575 kJ/day (2262–2518 kcal/d), which was calculated to result in them being in insufficient energy availability based on able-bodied criteria; however, total daily energy expenditure was not estimated (see Chapter 4).

Rather than rely on quantitative figures that may be imprecise, it is important for practitioners to recognise key clinical indicators of energy balance/imbalance to guide decisions around the adequacy of energy intake. It can generally be assumed that when an athlete is in energy balance (i.e. where energy consumed from the diet [E_{in}] is equal to the energy expended over the day [E_{out}]), their body mass will be stable, ability to train consistent without excessive fatigue, response to training effective and health and normal body functions (e.g. menstruation for females) maintained. An athlete who is consistently in energy surplus ($E_{in} > E_{out}$) over time will gain body mass in the form of body fat and/or lean tissue, depending on the type and amount of activity being undertaken. In contrast, while it might be logical to assume that an athlete who is consistently in energy deficit over time would lose body mass, this can often depend on how large the energy deficit is. The risks, consequences and assessment of low energy availability are outlined in Chapter 4. Other indices the practitioner can use include the ability of the athlete to complete all training sessions according to coach expectations, overall energy levels and mood state. An experienced practitioner will be able to recognise whether energy intake is within the "ballpark" of estimated energy expenditure or whether there appears to be a substantial imbalance between the two. Furthermore, dietary records or histories will provide qualitative information such as the nutrient density of the diet, food preferences, eating patterns over the day and in relation to training/exercise and day-to-day variety. Hence, there are many different ways a sports nutritionist can improve an athlete's diet to support their training needs that don't rely on accurate numerical representations of energy requirements or intake.

3.2.2 Changing Body Composition

During an athlete's lifetime, there will be periods where body composition changes as a result of growth and training responses. There may be other times where body composition is deliberately manipulated to optimise the athlete's physique characteristics for their sport – be that by increasing LBM for greater strength/power, reducing body fat or absolute mass or achieving a target weight in order to compete in weight category sports. Regardless of the desired change in body composition, it is important for the practitioner, athlete and coach to set realistic targets and provide adequate time to undertake the majority of changes so that the longer-term requirements of training are not compromised. It is also important that body composition be appropriately assessed (as will be described in Chapter 13) since body mass per se is not a sensitive marker of small but important changes in the components of body composition. The achievement of body composition goals often requires more than one season, especially when an athlete is still growing or is new to a sport, or there are other large changes being made to skill, fitness or strength. It is also important to minimise the loss of conditioning and changes in body composition that occur during breaks in training (i.e. during the off-season or while injured). For example, a recent case history of the 9-year career of an elite middle distance runner shows a gradual improvement in leanness over many seasons, but also a deliberate range in body mass and fat mass within a season as the athlete cycled between a higher level supporting training resilience and a lower level consistent with optimal race performance (Stellingwerff 2018).

The primary factors in changing body composition are the training stimulus and energy balance. Regardless of the macronutrient composition of the diet, long-term changes in body composition and mass occur most effectively when there is an imbalance between E_{in} and E_{out} (Manore and Thompson 2015). The principles of changing body composition are similar whether the goal is increased lean body mass or reduced body fat.

- The manipulation of energy intake should be relatively small (10%–20% of energy requirements or up to 2000 kJ or 500 kcal/day) but consistent. Larger increases in energy intake in order to gain lean body mass are likely to also result in substantial increases in body fat which often then has to be lost at a later time. Greater deficits are likely to increase the risk of low energy availability and compromise training capacity.
- Food should be consumed on a regular basis throughout the day. When losing body fat, the preference should be to change portion sizes rather than frequency of feeding. This is particularly important for athletes who train more than once a day, since the removal of midmeal snacks could potentially compromise recovery between training sessions by failing to optimise the delivery of nutrients within the recovery period. When gaining LBM, it may be necessary to add eating occasions to the day to create additional opportunities to consume energy, since increasing the size of the meals may cause gastric discomfort. There is also evidence to suggest that consuming protein-rich foods/fluids (such as milk or cheese) before bed promotes muscle protein synthesis overnight (Res et al. 2012).
- An even spread of protein intake should be maintained over the day (i.e. each meal/snack should contain some protein), as this will help preserve muscle mass and help manage the appetite. If preserving LBM while losing body fat is the goal, it may be useful to increase protein intake at meals to 0.3–0.4 g/kg body mass (BM, Moore et al. 2015).
- Carbohydrate intake should be maintained at a level that is adequate for the training load. Manipulating the glycaemic index (GI) and fibre content of carbohydrate-rich foods can be useful to manage satiety, where lower GI/higher fibre choices help improve satiety for those losing body fat, and higher GI/inclusion of some lower fibre sources may help athletes who find it

difficult to eat enough. Achieving adequate carbohydrate intake should take priority over the inclusion of other energy-dense macronutrients (e.g. fat, alcohol) in the diet, especially where body fat loss is the goal. However, this should not be to the detriment of the intake of essential fatty acids, nor should a carbohydrate intake in excess of needs be promoted.

- Nutrient requirements should be met within the athlete's energy "budget." When energy intake is reduced to assist with loss of body fat, it is important to focus on nutrient-dense foods and fluids and reduce the intake of energy-dense, low-nutrient choices. This may mean prioritising "whole" foods which deliver a range of key nutrients and food factors before/during/after training in preference to specialised sports products which often contain only a few targeted nutrients. Although an increased energy intake may be required during periods of LBM gain, this doesn't mean that the athlete should consume lots of nutrient-poor foods. Rather, the athlete should focus their meals and snacks on compact forms of nutrients that manage their appetite and gastrointestinal comfort.

Table 3.2 provides an example of how a day's diet could be manipulated either by increasing or decreasing energy content by 2000 kJ in order to promote body composition changes without compromising the principles of training nutrition.

3.2.3 Fuelling Training Sessions

An athlete's need to consume fuel sources prior to and during training are determined by their training status; the intensity, duration and type of session to be undertaken; the timing of subsequent training sessions; and the purpose of the training session. Most fuelling strategies target the body's carbohydrate reserves (muscle glycogen, liver glycogen and blood glucose), which are relatively small in comparison to the reserves of other body fuels (e.g. body fat). In many sports, reduced performance and fatigue are a consequence of the depletion of carbohydrate stores and our limited ability to convert other fuels (e.g. fat or amino acids) into the glucose desired by the central nervous system and muscle when it's working at moderate to high exercise intensities. This is particularly so when the training and competition schedules of athletes place a heavy demand on fuel.

Table 3.3 presents current recommendations for the consumption of carbohydrate throughout the whole day and with respect to a training session. Carbohydrate intakes should vary from day to day and across the training macrocycle in tune with the changing fuel requirements of the athlete's training load. It is also unnecessary to undertake all training sessions with high carbohydrate availability, and may even be beneficial in terms of promoting adaptations to the training stimulus to undertake some sessions in a glycogen-depleted state (Hearris et al. 2018; Impey et al. 2018; see Section 3.2.7). However, chronic periods of training with low carbohydrate availability may compromise both training capacity and mood state (Achten et al. 2004) or immune status (see Section 3.2.6). Furthermore, while it is well recognised that limiting carbohydrate chronically (by means of a high-fat, low-carbohydrate diet) can increase the muscle's fat utilisation, this strategy also reduces its ability to

TABLE 3.2
Example of Modifying a Training Diet to Alter Body Composition

Daily Intake Example	Changes to Increase by 2000 kJ/d for Mass Gain	Changes to Reduce by 2000 kJ/d for Body Fat/Mass Loss
7.30 a.m.: 1 cup cereal + 2 Tablespoons muesli + 150 mL light milk		Remove muesli but add a serving of fruit (e.g. berries on top of cereal)
Glass of juice		Omit juice
Gym 9–10 a.m.		
10 a.m.: after gym, 600 mL low-fat chocolate milk		
12.30 p.m.: 1 tuna and salad sandwich (light mayonnaise) with an apple	Add an extra sandwich	Add extra salad to sandwich
2.30 p.m. 1 muesli bar		Change snack to 1 slice wholegrain toast with honey
Swim training 3–5 p.m.		
5.15 p.m.: after training 200 g flavoured Greek yoghurt with 2 Tablespoons nuts		Reduce nuts to 1 Tablespoon
7.00 p.m.: 180 g grilled steak + 2 medium potatoes, carrots, broccoli, beans		Move dinner forward to 6.30 p.m., reduce the size of the steak to 120 g and increase the amount of vegetables
9 p.m.: 1 bowl of berries + 2 scoops of ice cream	Add 1 cup hot chocolate (light milk)	1 bowl berries + 1 scoop ice cream

Note: Example based on a 60-kg female swimmer: (2 training sessions/d).
Nutritional targets: 10,500 kJ/d for weight maintenance, 360 g carbohydrate, 90 g protein with 20 g protein delivered within 60 min of finishing each training session and the rest distributed over the day.

mobilise carbohydrate for high-intensity work (Burke et al. 2017a) and hence limits “top end” speed and the ability to change pace during exercise.

During training sessions in which exercise capacity is likely to be limited by insufficient carbohydrate availability (e.g., a single prolonged session or a session undertaken within a phase of heavy training), it may be beneficial to consume carbohydrate during the session. Such benefits include improved concentration, maintenance of skill, improved endurance and high-intensity exercise capacity (Stellingwerff and Cox 2014) and attenuation of the decline in immune cell function postexercise (Braun and Von Duvillard 2004). Table 3.3 provides guidelines for carbohydrate intakes that can optimise performance during exercise of different durations; the science behind these recommendations will be discussed further in Section 3.3.5. Many options of everyday foods and specialised sports products (e.g. sports drinks, gels, gummies or bars) can contribute to these targets according to the practicality of consumption and the need for other nutrients, including fluid. Figure 3.1 presents two case studies of athletes and their approximate daily

TABLE 3.3
Carbohydrate Needs for Training, Recovery and Fuelling

Daily Needs for Fuelling and Recovery

1. The following daily targets, especially when consumed acutely around a specific session, are intended to provide high carbohydrate availability when it is important to exercise with high quality and/or at high intensity. These theoretical recommendations should be fine-tuned with individual consideration of total energy needs, specific training needs and feedback from training performance.
2. For low-moderate exercise quality or intensity, it may be less important to achieve these carbohydrate targets or to arrange carbohydrate intake over the day to optimise availability for specific sessions. In these cases, carbohydrate intake may be chosen to suit energy goals, food preferences or food availability.
3. In some scenarios, when the focus is on enhancing the training stimulus or adaptive response, low carbohydrate availability may be deliberately achieved by reducing total carbohydrate intake or by manipulating carbohydrate intake related to training sessions (e.g. training in a fasted state, undertaking a second session of exercise without adequate opportunity for refuelling after the first session).

Situation	Description	Carbohydrate Targets (per kg body mass or per hour)
Light training load	Low-intensity or skill-based activities	3–5 g/kg/d
Moderate training load	Moderate exercise programme (e.g. ~1 h per day)	5–7 g/kg/d
High training load	Endurance programme (e.g. 1–3 h/d mod-high-intensity exercise)	6–10 g/kg/d
Very high training load	Extreme commitment (e.g. >4–5 h/d mod-high intensity exercise	8–12 g/kg/d
***Acute Fuelling Strategies* to promote high carbohydrate availability for optimal performance in competition or key training sessions**		
General fuelling up	Preparation for events <90 min exercise	24 h @ 7–12 g/kg as for daily fuel needs
Carbohydrate loading	Preparation for events >90 min of sustained/intermittent exercise	36–48 h @ 10–12 g/kg BM/d
Speedy refuelling	<8 h recovery between 2 fuel demanding sessions	1–1.2 g/kg/h for first 4 h, then resume daily fuel needs
Pre-event fuelling	Before exercise >60 min	1–4 g/kg consumed 1–4 h before exercise • Timing, amount and type of carbohydrate foods and drinks should be chosen to suit the practical needs of the event and individual preferences/experiences.

(*Continued*)

TABLE 3.3 (*Continued*)
Carbohydrate Needs for Training, Recovery and Fuelling

Situation	Description	Carbohydrate Targets (per kg body mass or per hour)
Acute *Fuelling Strategies* to promote high carbohydrate availability for optimal performance in competition or key training sessions		
During brief exercise	<45 min	Not needed
During sustained high-intensity exercise	45–75 min	Small amounts including "mouth rinse" • Frequent 5–10 s contact of the mouth and oral cavity with carbohydrate can stimulate parts of the brain and central nervous system to enhance perceptions of well-being and increase self-chosen work outputs.
During endurance exercise including "stop and start" sports	1–2.5 h	30–60 g/h • Provides a source of muscle fuel to supplement endogenous stores. • A range of everyday foods and specialised sports products, ranging from solids to liquid, may be useful. • Opportunities to consume foods and drinks vary according to the rules and nature of each sport. • Should be practised and integrated into a plan that suits individual goals including hydration needs and gut comfort.
During ultra-endurance exercise	>2.5–3 h	Up to 90 g/h • As above, but higher intakes of carbohydrate are associated with better performance. • Products providing multiple transportable carbohydrates (glucose:fructose mixtures) achieve high rates of oxidation of carbohydrate consumed during exercise.

Source: Adapted from Thomas, D.T. et al. 2016. *Medicine and Science in Sports and Exercise* 48:543–68.

a. The case for a female adaptive rower

The following meal plan is based on a female adaptive rower who trains two to three times a day most days including a mix of low-intensity aerobic work, strength / resistance training and high-intensity repeat effort work. Assuming body mass of 68 kg, approximate CHO requirements for this day are 6-8 g/kg BM (410-540 g).

Because morning session includes high intensity work, and 2 harder sessions in the day

Sports drink provides carbohydrate at 30-60 g/hr during training

Wholegrain cereals are rich in b-group vitamins and are a great source of carbohydrate and fibre. Toast can be added to top-up carbohydrate intake in order to assist recovery between sessions

Roll is an excellent source of lean protein with carbohydrate. Fruit salad provides a rich source of antioxidants and is a great option when out. Yoghurt adds to daily calcium and protein intake.

Provides adequate protein to assist muscle repair and carbohydrate to start muscle refuelling.

Rice is a rich source of carbohydrate - the quantity should be scaled to match daily fuel needs. Fruit and vegetables are rich in antioxidants, whilst lean beef is an excellent source of iron and protein.

Pre-Training Snack (6:00am)	Slice of toast with honey	20 g CHO
Training (6:30am)	6km row with race pace efforts 500ml sports drink plus water during session	30 g CHO
Breakfast (8.30am)	1 cup mixed Wholegrain cereal with low-fat milk with mixed berries and ½ glass juice	85 g CHO
Work (9.30-1.30)	Skinny latte with 2 rye crispbreads with jam	40 g CHO
Lunch (1:30pm)	Chicken and salad roll Fruit Salad with yoghurt	70 g CHO
Afternoon Snack (4.15pm)	2 rice cakes with peanut butter and banana	35 g CHO
Afternoon Training (4:30pm)	Gym water during session	
Post-training drink while at ice-bath (6:00pm)	Liquid Meal Supplement (provides ~20g protein and ~40g carbohydrate) PLUS a piece of fruit	60 g CHO
Dinner (7.00pm)	Lean beef and vegetable stir-fry (assorted vegetables included) Brown Rice (1 cup)	60 g CHO
Supper (9pm)	Sliced peaches with custard	30 g CHO

FIGURE 3.1 Case studies for varying carbohydrate intake. (*Continued*)

carbohydrate needs and how this might be distributed across the day and in relation to training. It is important to remember that these are recommendations only, and individual athletes will need to trial different strategies to understand how to best meet their own needs. In particular, the total quantity of carbohydrate may require some modification with Para athletes to fit within their total energy budget.

3.2.4 Practising Competition Strategies of Fuelling and Hydration

Most athletes will have heard the phrase "never try anything new on race day." Training sessions not only drive the development of physiological capabilities and specific skills, they can also present opportunities to practise and refine competition nutrition strategies. Such practise is not only of practical importance (e.g., developing the skills to drink while running, or to handle a bike while obtaining foods and fluids from a feed zone in a cycle race), but may also provide a physiological advantage. There is evidence, at least in endurance exercise, that the gut can be trained to absorb carbohydrate to be used as a fuel source during exercise (Cox et al. 2010). It may not be necessary to consume carbohydrate in every training session; however, certain

b. The case for a male track runner

The following meal plan is based on an 80kg male track athlete with cerebral palsy. Track athletes often train twice a day, and although one of these may be long the actual amount of work done is often quite small (2-3 minutes total of high intensity work). Approximate CHO requirements for this day are 5 g/kg BM (400 g).

Breakfast (7:00am)	2 slices wholegrain toast one with an egg, one with yeast spread	30 g CHO	Light breakfast due to high intensity work in track session. Doesn't want to feel sick during training
Training (9:00am)	Track session – warm up, 3 x 60m, 3 x 80m with 5 min break Sips of sports drink as CHO mouth rinse	10 g CHO	Mouth rinse useful for high intensity work since lighter breakfast
Immediately post training (10.30am)	Large smoothie made with milk, yoghurt, honey and fruit	60 g CHO	Session does not require substantial refuelling but does require protein and snack can be larger due to smaller breakfast
Lunch (1pm)	Large meat and salad roll Plus piece of fruit	90 g CHO	
Afternoon Training (3:00pm)	Gym session – core stability, stretch, form work		
Post-training snack (4:00pm)	200g flavoured Greek yoghurt Muesli bar	50 g CHO	Recovery snack not strictly necessary however provides fuel and protein between lunch and dinner
Dinner (6.30pm)	Spaghetti bolognese with salad Garlic Bread – homemade	100 g CHO	
Supper	Bowl of fruit with custard or ice cream	40 g CHO	

FIGURE 3.1 (Continued) Case studies for varying carbohydrate intake.

sessions can be targeted for event practise, especially in the competition-specific phase of preparation. Since fluid needs are highly individualised (as outlined in Chapter 5), athletes should understand their own fluid requirements under different training and competition settings and develop fluid intake strategies that minimise deficits over a training session and over the whole day.

COMMENTARY BOX 3.1

COACH'S INSIGHT: What do you think is the most important thing a sports nutrition practitioner can do to assist your athletes?

> Teach them how to eat right, including how to do shopping and cook well. It's important for the sports nutrition practitioner to watch what the athlete actually does in training so that they understand how much food they need to eat. For example, my athletes don't need to eat as much as able-bodied track athletes do because they don't undertake the same volume of training since they fatigue more quickly.

Iryna Dvoskina, Athletics (track) coach of multiple Paralympic medallists

3.2.5 Recovering between Workouts

The modern approach to recovery nutrition incorporates a holistic delivery of nutrients to support the responses of all body systems following the "stressor" of an exercise bout. The requirement for each component of recovery nutrition depends on the nature of the exercise bout itself – for example, not all exercise bouts will deplete muscle glycogen stores or create a large fluid deficit. Not all the sessions that are now regularly incorporated into an athlete's "training plan" require a proactive approach to recovery nutrition – for example, Pilates or yoga, a stretching/recovery gym session, a skill session, 30 min walk or an "easy" swim may be undertaken without a specialised plan of recovery eating. The development of a recovery eating plan requires understanding of the physiological stresses involved in each training session, the goals of each session and subsequent workouts and the athlete's total training demands. It is also important to recognise that food and drinks consumed to promote recovery after a training session may not need to add extra kilojoules/energy to the day's intake. In many cases, larger meals may need to be reduced in size to create an opportunity to add a recovery snack into the day. Alternatively, the timing of training and/or the meal could be manipulated to coincide more effectively. Four key components of recovery nutrition, as summarised in Table 3.4, are refuelling, rehydration, repair/adaptation and revitalisation.

3.2.5.1 Refuelling

The need for proactive refuelling between two training sessions depends on the glycogen demands of each session and period of time between them. Since glycogen storage occurs at a rate of about 5% per hour, it may take a day of carbohydrate-rich intake to fully restore or load glycogen between glycogen-depleting exercise bouts (Coyle 1991). When the program involves two bouts of glycogen-limited exercise within 8–12 h, the athlete should promote effective refuelling by consuming carbohydrate-rich foods and drinks providing 1–1.2 g/kg/h soon after exercise to contribute towards their total daily carbohydrate requirements (as per Table 3.3). Such strategies will optimise the replenishment of muscle glycogen stores as well as promote the activity of many of the immune system white cells (Bishop et al. 2009).

3.2.5.2 Rehydration

Replacing the fluid and electrolytes lost as sweat is an important component of postexercise recovery, especially when the losses are substantial, the environment is hot and preparation time for the next session is relatively short. Since a rehydration plan will also need to address ongoing sweat and urine losses, restoration of fluid balance in the hours after exercise require the individual to consume a fluid volume equivalent to ~125%–150% of the deficit created by the exercise bout. Replacement of sweat sodium losses contributes to rehydration goals by preserving thirst and minimising urine losses (Maughan et al. 1997). This can be achieved by choosing sodium-containing fluids (such as milk or sports drinks) or by eating a meal or snack that includes foods that are salt containing (such as bread, cheese, many breakfast cereals, yeast-extract spreads) or have salt added to them in preparation (such as eggs and most main meals).

TABLE 3.4
Summary of Eating for Recovery

Issue	Key Sessions Requiring Proactive Strategies	Overview of Recommendations	Examples of Suitable Food Choices
Refuelling	High-intensity exercise or prolonged endurance activity (>60 min) where another training session is to be undertaken within 8–10 h	1 g carbohydrate/kg BM/h for 4 h	Bread, fruit, cereals, rice cakes, crackers Pasta, rice, potatoes, sweetened dairy products (flavoured milk, yoghurt, custard)
Rehydration	Activities which have induced a substantial (>2%) loss in body mass	120%–150% of fluid losses consumed over the next few hours	Fluids containing electrolytes (especially sodium) such as sports drinks, milk, electrolyte solutions; or water consumed with food
Protein synthesis for repair and adaptation	Resistance exercise, high-intensity activity, prolonged endurance exercise, high-impact activity where muscle damage is likely	20–25 g high quality protein consumed soon after exercise, with evidence to support repeated small doses of protein every few hours through the day and perhaps a larger serving (40 g) prior to sleep	Milk proteins (e.g. milk, yoghurt, custard) Meat, poultry, fish, eggs
General health and immune system support	Resistance exercise, high-intensity activity, prolonged endurance exercise, high-impact activity where muscle damage is likely	Consume a range of whole foods wherever possible	Antioxidant nutrients (brightly coloured fruits & vegetables, wholegrain cereals), omega-3 fatty acids (oily fish), probiotics (yoghurt)
Putting it all together		Protein + carbohydrate + electrolytes + micronutrients	Fruit smoothies, berries and sweetened yoghurt, tuna salad sandwiches, meat/chicken and chicken stir fry with rice or noodles, iron-fortified cereals with milk and fruit toppings, omelette with mushrooms and parsley on toast

3.2.5.3 Repair/Adaptation

Over recent years, there has been an increased appreciation that optimal adaptive responses to training represent an interaction between the exercise stimulus and the intake of protein, particularly of individual amino acids such as leucine. Research has provided strong evidence that the intake of moderate amounts of protein soon after training maximises muscle protein synthesis (Burd et al. 2011), not only for the development of muscle mass/strength but also for the synthesis of muscle proteins involved in endurance exercise (e.g. enzymes, mitochondria) and hormones which regulate metabolism and immune function. Combining protein with carbohydrate-rich meals and snacks consumed after exercise is also advantageous in optimising glycogen synthesis in situations where muscle damage has occurred or where carbohydrate intake is suboptimal (Betts and Williams 2010).

While the daily protein intakes recommended to athletes may be elevated to 1.2–1.7 g/kg body mass/day, it appears that the timing and frequency of this intake are of the most importance to capitalise on the increased rates of muscle protein synthesis that occur for at least 24 h after an exercise bout. To optimise the immediate postexercise response, it appears that athletes should consume 20–25 g (or 0.25 g/kg body mass) of high-quality protein sources containing 2–3 g leucine (e.g. dairy, meat products, eggs) soon after exercise (Moore et al. 2015). This can be provided as a fluid (such as milk), a snack or components of a meal, depending on the timing of the exercise and the athlete's total energy budget. While these protein targets can be easily obtained through food sources, there is also a range of protein powders, such as whey protein, and liquid meal supplements based on dairy which can be useful after exercise as a compact, easily transportable source of protein. As outlined in Chapter 14, care must be taken with using any nutritional supplement to thoroughly check ingredients, especially where athletes may be subject to antidoping regulations.

3.2.5.4 Revitalisation

Many micronutrients (vitamins, minerals, antioxidants, phytochemicals) are important cofactors in metabolism and may contribute favourably to recovery processes after exercise. Although we are uncertain about the effects of regular exercise on micronutrient requirements, it is prudent for athletes to take advantage of opportunities to increase their intake of micronutrients and phytochemicals by consuming a wide range of nutrient-rich foods whenever possible. While sports foods and supplements may meet targets for isolated macronutrients such as protein and carbohydrate, whole foods are likely to offer the advantages of a greater range and quantity of micronutrients. Furthermore, the combination of foods within a meal or snack can strategically optimise the absorption of nutrients (e.g. combining vitamin C–containing foods/fluids such as citrus fruits, tomatoes or peppers with iron-rich plant products such as iron-fortified breakfast cereals, green leafy vegetables and legumes to enhance iron absorption). Focussing on nutrient-dense foods is particularly important for those who are have a relatively low energy budget since achieving all of the micronutrient requirements is more difficult when total food intake is restricted.

COMMENTARY BOX 3.2

ATHLETE INSIGHT: What sports nutrition practises have had the biggest impact on your training capability or performance?

> Pre- and postcompetition nutrition. Eating more of a balanced diet to cover the level of training that I do.

AJ, Para canoe

> Eating right and enough, specifically for pre-, during and postrecovery. With this slight change in diet, it helped me to train and recover well and eventually develop more power and explosiveness for my sprint events.

Carmen Lim, Para swimmer (S8)

3.2.6 Minimising Illness and Injury

During periods of heavy training and competition, long-haul travel, low energy availability and high levels of psychological stress, athletes can be at increased risk of infectious illnesses, especially of the upper respiratory tract (URTI; Bermon et al. 2017, Walsh 2018) and injuries related to their sport (Rogalski et al. 2013). For example, Paralympic swimmers showed elevated salivary immunoglobulin A, alpha-amylase and cortisol levels across both a 16-week preparation phase of training (elevated training load) and a 10-day competition period despite a reduced training load, indicative of a stress response (Sinnott-O'Connor et al. 2018). Injury and illness result in the loss or modification of training sessions, which interrupts the optimal accumulation of the adaptive training response. If this occurs at a crucial time in race preparation or immediately prior to competition, the consequences can undo months, if not years, of progress towards an athlete's goals. Infection can also place fellow athletes/team members at risk of illness. There are a number of dietary factors which have been linked to the immune system and may require consideration in the athlete's eating plans.

3.2.6.1 Carbohydrate and Total Energy Intake

Maintaining adequate energy and carbohydrate intake, especially during periods of heavy training or acute changes in training stress, are important components in reducing the degree of detrimental immune disturbances which result from exercise (Walsh 2018). Prolonged negative energy balance and/or low energy availability may result in the inability to supply all dietary nutrients required to support immune function. Carbohydrate appears to be more effective at minimising immune perturbations when consumed during exercise (Bermon et al. 2017), although it may not specifically reduce the incidence of URTI. Some injuries may also result from fatigue or poor concentration due to poor energy or carbohydrate availability.

3.2.6.2 Protein and Amino Acids

Protein has an important role in many aspects of immune function and in recovery from injury. While it is uncommon for athletes to consume insufficient amounts of protein, there are some individuals who may be at risk due to their energy budget or their dietary preferences, such as vegans. Insufficient total dietary protein intake impedes wound healing and is required for the synthesis of collagen and other proteins necessary for repair postinjury (Slater et al. 2015). It is particularly important to increase total, and frequency of, protein intake during immobilisation (such as postsurgery) to support muscle protein synthesis and prevent muscle protein loss (Slater et al. 2015).

Sports scientists have been interested in the role of the nonessential amino acid glutamine in immune function related to exercise. Glutamine can be used as an energy substrate by a number of immune cells, and low blood concentrations of glutamine have been found to coincide with immunodepression (Castell 2003). Since plasma glutamine concentrations are decreased following prolonged or strenuous exercise, both acutely and more chronically, there has been interest in supplementing with glutamine to improve immune function (Bermon et al. 2017). Although supplementing with glutamine has been shown to prevent the exercise-induced fall in plasma glutamine, this has had no effect on immune cell number and function after exercise and inconsistent effects on symptoms of illness (Bermon et al. 2017, Castell 2003). Therefore, to date there is no evidence to support supplementation with glutamine, other than to ensure adequate overall dietary protein from a range of food sources in order to ensure an appropriate balance of individual amino acids.

Branched chain amino acids (BCAAs: leucine, isoleucine and valine) have also been a topic of investigation for both muscle protein synthesis and immune function. BCAA metabolism could indirectly influence the immune response by producing nitrogen for glutamine synthesis (Bermon et al. 2017). Controlled studies have so far failed to provide consistent support for the supplementation of BCAA in reducing exercise-induced immunosuppression, and sufficient total dietary protein intake is of greater value for muscle protein synthesis than just BCAA alone (Moore et al. 2015).

3.2.6.3 Fatty Acids

Fatty acids have numerous roles in the body, including influencing inflammation via their effect on prostaglandins. In essence, saturated fatty acids promote inflammatory processes, while unsaturated fatty acids have anti-inflammatory properties (Bermon et al. 2017). It is now well recognised that omega-3 fatty acids have both anti-inflammatory and immune-modulatory effects that can benefit athletes (Bermon et al. 2017, Slater et al. 2015), although it must be recognised that some inflammation is part of the adaptive processes for exercise training. Their role in reducing concussion symptoms is outlined in Chapter 12. Athletes should therefore be encouraged to consume adequate dietary sources of omega-3 fatty acids (oily fish, flax and chia seeds) while ensuring a balance of saturated to unsaturated fatty acids that follows dietary guidelines. Where high levels of inflammation are present over an acute period, omega-3 fatty acid supplements may be considered beneficial; however, optimal doses have not been agreed upon (Slater et al. 2015).

3.2.6.4 Antioxidants and Polyphenols

It is well recognised that exercise induces oxidative stress – indeed, this appears to be one of the mechanisms driving the adaptations to training (Kawamura and Muraoka 2018). Oxidative stress can also lead to the damage or modification to immune cells and tissues resulting in an impairment of function (Bermon et al. 2017); hence, a number of antioxidant nutrients have been investigated for the purpose of improving immune status.

There has been a long history of research on vitamin C in relation to preventing upper respiratory tract infections ("colds") and boosting immune function. Indeed, there is some evidence that supplementation with vitamin C, together with zinc, at the onset of cold symptoms can reduce the duration and impact of a cold (Hemila and Chalker 2013). In addition, megadoses of vitamin C taken after an ultraendurance competition have been shown to reduce the incidence of infection in the postcompetition phase (Peters et al. 1993). However, there is limited evidence to support daily vitamin C, vitamin E or zinc supplementation in athletes. Indeed, while megadoses of these nutrients may suppress cortisol and interleukin-6 responses to exercise (Fischer et al. 2004), they appear to have minimal effects on most aspects of immunity and incidence of upper respiratory-tract illnesses in well-nourished individuals, even in extreme environments (Bermon et al. 2017, Walsh 2018).

The potential benefits of supplementing with antioxidants for immune function need to be counterbalanced by emerging evidence of the potential for antioxidant supplements to diminish the adaptive response to exercise (Ristow et al. 2009) and slow the recovery of muscle function after eccentric exercise (Close et al. 2006). Therefore, the preference is to promote an increased intake of antioxidant-rich foods, especially in periods of heavy training, over supplementation with high doses of antioxidants (Kawamura and Muraoka 2018).

The bioflavonoid quercetin is another antioxidant which has been of recent interest in the sports nutrition literature as an immune stimulator with antimicrobial and antiviral properties, and as an anti-inflammatory agent (Davis et al. 2009). Despite promising research in rodents, the benefits of quercetin have not translated well into the human literature, with no evidence to suggest an impact on immune cells and very limited evidence to support changes in immune function following supplementation (Walsh et al. 2011), but potential to improve exercise performance (Somerville et al. 2017). While further research is necessary, it may be prudent to focus on ensuring high intakes of quercetin- and other polyphenol-rich foods such as berries, green tea, wine, onions, apples, cherries and green leafy vegetables.

3.2.6.5 Probiotics

Probiotics have been associated with improvements in gut barrier function, an important first "line of defence" in the immune system. There is evidence that probiotic intake can enhance the immune system, improve intestinal tract health and reduce prevalence of allergy in susceptible individuals (Bermon et al. 2017). Several large studies in athletes have provided evidence of reduced number of illness symptom days (Bermon et al. 2017, Cox et al. 2008, West et al. 2011); reduced severity of gastrointestinal symptoms, especially during long-haul travel (Walsh 2018, West et al. 2011) and improved symptoms in fatigued athletes with an identifiable immune deficiency (Clancy et al. 2006). Since there is a synergistic effect between food compounds and probiotic cultures, dairy products such as yoghurt and acidophilus milk are a good avenue for the consumption of probiotics. Alternatively, probiotic supplements may be useful in athletes.

3.2.6.6 Calcium

Injury and chronic leg pain related to the chronic bone microtrauma known as stress fractures are common in many sports (Sanborn et al. 2011). While the aetiology of stress fractures is complex and multifactorial, low bone density is considered a major contributing factor (Scofield and Hecht 2012). While weight-bearing and high-impact exercise can promote bone strength, there is increasing evidence of inadequate bone density in a range of athlete populations, including cyclists (Scofield and Hecht 2012). While inadequate energy availability is an important risk factor in impaired bone health (see Chapter 4), a key nutrient in optimising bone density is calcium. Although recommended dietary intakes of calcium vary between countries, it is well recognised that the richest and most well absorbed sources of calcium are dairy products. Unfortunately, many athletes reduce or limit their dairy intake due to their concerns regarding weight (body fat) gain and/or lactose intolerance. However, there is now a large body of information that supports a positive role for dairy products in both body composition management and the achievement of sports nutrition goals. Furthermore, a calcium-rich pre-exercise meal has been shown to reduce the rise in bone reabsorption markers resulting from a prolonged exercise bout (Haakonssen et al. 2015). Therefore, it is important for athletes to include sufficient dairy products (and other calcium-rich food sources) in their diet to achieve calcium requirements, using low-lactose variants where lactose intolerance has been diagnosed or calcium-fortified alternatives if dairy intolerant or vegan.

3.2.6.7 Iron

Iron deficiency, with or without anaemia, can impair muscle function and limit work capacity. While not directly related to immune function or injury, low iron status will lead to compromised training adaptations and exercise performance and is therefore important to prevent in athletes (Deakin and Peeling 2015; Thomas et al. 2016). Iron requirements for females may be increased by up to 70% from estimated average requirements (Thomas et al. 2016). The ability to achieve dietary iron needs is influenced by total energy intake and the intake of animal protein sources. Athletes should be monitored for iron status, especially if they are growing, vegetarian/vegan, females in higher-risk sports (such as running), regular blood donors, have low energy budgets or are going to train at altitude (Deakin and Peeling 2015, Thomas et al. 2016). Increasing dietary iron intake is the first line of prevention/treatment of iron deficiency, including the intake of both heme and nonheme iron sources combined with foods rich in vitamin C. Oral iron supplementation may be necessary to achieve normal iron status in those who are deficient. Iron supplements of around 100 mg elemental iron in a ferrous form are considered the best absorbed, with recent evidence suggesting supplementing every other day being equally beneficial with fewer side effects (Deakin and Peeling 2015). Indiscriminate use of iron supplements without iron deficiency are not recommended.

3.2.6.8 Vitamin D

Vitamin D is a nutrient classified as a fat-soluble vitamin, which acts functionally as a hormone. Our primary source of vitamin D is ultraviolet B (UVB) radiation from sunlight, and recent studies have found vitamin D deficiency and suboptimal status in many populations, with athletes being no less susceptible (Bermon et al. 2017). Of particular concern are athletes who train predominantly indoors, have dark skin pigmentation, live at latitudes >35° north or south of the equator and/or who expose relatively small skin surface area to sunlight. Vitamin D has many roles within the body, the most well recognised being in optimising bone strength through its integral role in the uptake of calcium into bone. In addition, insufficient vitamin D status has been shown to reduce immune function and muscle strength (Bermon et al. 2017, Cannell et al. 2009). While vitamin D is a dietary nutrient, dietary sources are generally unable to alter vitamin D status substantially enough to reverse a clinical deficiency. Instead, safe sun exposure as advised by most national cancer councils or public health authorities is promoted, with regular checks of vitamin D status being undertaken in athletes, particularly at the end of summer and more often in those at risk of inadequate exposure. Appropriate supplementation should be organised in those found to have insufficient (<30 ng/mL or <75 nmol/L) or deficient (<20 ng/mL or <50 nmol/L) vitamin D levels (see Chapter 12; Scaramella et al. 2018), especially during the winter months (Bermon et al. 2017, Walsh 2018). Athletes are equally cautioned against the use of excessive vitamin D doses due to risk of toxicity (Bermon et al. 2017).

3.2.7 Special Issues and Controversies in Training Nutrition

Technological advances have allowed a more in-depth perspective on the metabolic response to exercise and nutrition. As is often the case, this can raise more questions than it answers, but it also initiates new insights into the complex interactions that occur within the human body in response to various manipulations of exercise and diet. Currently, there are a number of areas of research that may further refine and individualise the practise of sports nutrition, which have been summarised in Table 3.5.

Although performance is maximised when training is undertaken with high carbohydrate availability (i.e. glycogen stores and additional carbohydrate intake matched to the fuel cost of the event), recent studies of the signalling pathways which promote the adaptations to training show greater increases in cellular transcription factors and protein expression when the same exercise is undertaken in a low-glycogen environment (for reviews, see Hearris et al. 2018, Impey et al. 2018). Furthermore, withholding carbohydrate intake to delay the restoration of glycogen following a bout of exercise may prolong the period of enhanced cellular signalling (Impey et al. 2018). The first investigations of the functional benefits of "train low" strategies involved chronic periods (3–10 w) in which subjects undertook some (e.g. 50%) or all of their workouts with low carbohydrate availability; this was achieved either by

TABLE 3.5
New Issues in Sports Nutrition

Issue	Theme	Overview	Current Recommendations
Optimising adaptation to training	"Training low" with carbohydrate (CHO) may enhance training adaptations	Undertaking exercise with low CHO availability (in particular low muscle glycogen, and to a lesser extent lower blood glucose) may amplify the training stimulus and increase the expression of enzymes that promote fat metabolism. Restricting CHO intake in the hours after a key exercise session to delay the restoration of muscle glycogen may prolong the period of enhanced adaptation and cellular adaptation (= "recover low")	Consider targeting some training sessions during the "base" phase of training for lowered carbohydrate state, either by training fasted first thing in the morning or consuming minimal CHO between two sessions undertaken on the same day. An efficient sequence of strategies involves undertaking a key training session with high CHO availability (to promote training quality), restricting CHO intake during the recovery period over the day or overnight (to extend the period of adaptation), then undertaking the next moderate-intensity session in a fasted state (train low to amplify adaptation)
	Antioxidant supplements may block training adaptations	Oxidative stress may be important as a signal that promotes adaptation to the training stimulus. Antioxidant supplements may block this signal and reduce the adaptation to an exercise bout	Choose a diet rich in sources of a range of antioxidants during most training periods. Consider antioxidant supplements only if there is an additional "stressor" (such as altitude, heat) or in periods of frequent competition (e.g. tournaments) where the need for recovery outweighs the need to drive training response
Periodising nutritional goals to phase of training	Off season	Minimise changes in body composition, training usually very light and nonspecific	Be aware of energy-dense foods and fluids (including alcohol) and modify energy intake to meet reduced energy needs
	Base phase	High-volume training, best opportunity to manipulate body composition	Target specific body composition changes through manipulation of energy intake

(*Continued*)

TABLE 3.5 (*Continued*)
New Issues in Sports Nutrition

Issue	Theme	Overview	Current Recommendations
	Specific competition preparation	Training increases in intensity, often with specialised periods in different environments (e.g. heat, altitude) Increase in skills and tactical training in team sports	Increase carbohydrate intake to match intensity in training Consume a source of high-quality protein and carbohydrate soon after training to promote refuelling and adaptation Consider the use of supplements carefully Practise competition fuelling and hydration strategies
	Taper for competition	Intensity usually remains higher while volume decreases Energy requirements usually fall Opportunities to eat increase but appetite may not fall in line with reduced training load	Be aware of lowered energy expenditure and increased opportunities/time to eat (including boredom eating) to prevent any body fat gains during this time Consider carbohydrate loading for events > 2.5 h duration
Individualising goals to special needs of sport	Endurance sports	Maintenance of high power to weight ratios creates interest in achieving low body mass and body fat levels Carbohydrate availability during event promotes performance and needs to be practised during training	Choose a suitable competition weight that can be achieved safely and without chronic low energy availability Periodise nutrition according to microcycle and macrocycles of training Practise race day nutrition strategies to promote physiological and behavioural characteristics that enable them
	Team sports	Differences in activity patterns and game roles among team members may require different nutrition programs Competition formats may include weekly fixture or tournament formats Team athletes are at greater risk of poor alcohol practises than other athletes, particularly after the match or during the off season	Individualise nutritional programs to the needs of each player as well as the period of the sporting calendar Promote recovery after matches whether in tournament or weekly fixture Promote sound nutrition practises after matches and during off season, particularly with regard to alcohol intake

(*Continued*)

TABLE 3.5 (*Continued*)
New Issues in Sports Nutrition

Issue	Theme	Overview	Current Recommendations
	Weight category sports	Emphasis on low body fat levels for weight class Culture within sport to train above weight division Emphasis on weight creates an increased risk of low energy availability/issues with eating and body image	Choose a weight division that can be achieved safely and with minimal stress Choose nutrient-dense foods, sufficient carbohydrate to support high-intensity training, and a good spread of high-quality protein over the day to meet nutritional goals Rehydrate/refuel immediately after weigh-in according to the techniques used to make weight
	Power/strength sports	Goals are to enhance power & strength and possibly muscle hypertrophy Culture of interest in supplements and high protein intakes Competitive events often involve multiple throws, lifts or rounds	Consume a diet high in energy to support high lean mass Enable adequate carbohydrate intake to fuel resistance training sessions Consume adequate, but not excessive, protein and spread protein intake over the day Consume a source of high-quality protein (20–25 g) soon after resistance workouts
	Skill sports	Heavy reliance on concentration and fine motor skills, often over extended periods of time Culture within sport to consider impact of nutrition on performance to be minimal Often avoid eating/drinking precompetition due to potential impact on gut comfort and heart rate	Consume a nutritionally balanced diet to optimise health, well-being and body composition Commence training and competition in a hydrated state Consume a pretraining/competition meal which ensures stable blood glucose concentrations and achieves gut comfort

scheduling two training sessions close together without opportunity for refuelling before the second one, or by undertaking sessions in a fasted state and without further carbohydrate intake (Hearris et al. 2018). While the "train low" condition was associated with enhancements of the cellular response to exercise, such as greater increases in glycogen stores and enzymes associated with fat utilisation, only one study (undertaken in previously untrained subjects) has reported that this was associated with a better performance outcome (Hansen et al. 2005). One explanation for the failure of enhanced cellular characteristics to translate into a competitive edge is that "train low" strategies are associated with an impaired capacity to train at high intensity/power (Yeo et al. 2008); this may cancel out other benefits and be counterproductive to overall performance. More recent investigations in subelite athletes (Marquet et al. 2016) and case studies of elite athletes (Stellingwerff 2012) have shown that a more sophisticated periodisation of "train high," "train low" and "sleep/recover low" strategies according to the goal of each training session can integrate the athlete's ability to both train hard and benefit from enhanced adaptation. This has led to clear enhancements in the performance gains from a training block in groups of subelite athletes (Marquet et al. 2016), but the case for elite athletes is less certain (Burke et al. 2017a, Gejl et al. 2017). Further investigation is warranted and the latest sports guidelines include acknowledgment of potential benefits from a personalised approach to manipulating carbohydrate availability within the training diet (Jeukendrup 2017a, Thomas et al. 2016), especially when there is good understanding of the specific nature of the different strategies and their sequencing within a training program (Burke et al. 2018).

Finally, there has been a recent resurgence of interest in long-term adaptation to low-carbohydrate high-fat (LCHF) diets, with the goal of enhancing the muscle's capacity to use its relatively unlimited fat stores as an exercise fuel, particularly during endurance events (Noakes et al. 2014, Volek et al. 2015). This has been a popular idea at various phases in the evolution of sports nutrition, with the most recent iterations being a 5–6 day adaptation to a LCHF (~65% energy as fat and 2–3 g/kg/d CHO) followed by restoration of glycogen and carbohydrate intake during the endurance event, and the chronic ketogenic LCHF diet (< 50 g/d carbohydrate, ~75%–80% fat). This former approach was well investigated for a decade (1998–2008), as a periodised preparation to prime both fat and carbohydrate oxidative pathways in preparation for an endurance event. Although it was shown to retool the muscle to upregulate fat utilisation, it was later recognised that CHO oxidation pathways were impaired due to downregulation of key enzymes, including the pyruvate dehydrogenase system, leading to an inability to support higher intensity exercise despite the availability of carbohydrate supplies (for review, see Burke 2015b). The latter example of the ketogenic LCHF diet re-emerged in 2013 as a long-term strategy to increase fat utilisation while also achieving chronic exposure to high levels of circulating ketone bodies (Noakes et al. 2014, Volek et al. 2015). Again, there is evidence of a significant increase in muscle capacity to use fat as a fuel source (e.g. up to triple the normal rates of utilisation) associated with chronic (>3 w) adaptation to this diet (Burke et al. 2017a, Phinney et al. 1983, Volek et al. 2016). However, this is associated with an increase in the oxygen cost of ATP production, which becomes self-limiting as exercise intensities reach >75% of maximal aerobic capacity and the muscle's oxygen supply becomes the limiting factor in fuel production (Burke et al. 2017a). Indeed, such enhancement of fat utilisation mostly applies to ultra-endurance events in which the contribution of higher-intensity pieces that require the superior economy of carbohydrate oxidation is minimal and/or in which the athlete is unable to consume sufficient carbohydrate to maintain adequate carbohydrate availability (Burke 2015b). In most conventional events, particularly for elite Para athletes, success is dictated by high rates of energy production from economical fuel sources, and strategies that increase fat utilisation are associated with impairment of the capacity for exercise at intensities around the so-called lactate threshold (Burke et al. 2017a, Havemann et al. 2006).

3.3 COMPETITION NUTRITION

Competition nutrition presents a different range and level of issues to the athlete than those encountered in the training phase. Additional challenges include the overlay of pressure to achieve success, the presence of rules or a competition timetable that interfere with desirable nutrition practises, issues related to travel, an unfamiliar environment and communal living and a limited number of opportunities to undertake high-level practise for specific competition scenarios. On the other hand, the competition environment can support good nutrition practises in terms of presenting a large incentive to get things right, or providing an infrastructure of aid stations, feedzones or other mechanisms of making nutrition support available before, during and after events. Sporting competitions vary according to a range of factors – the intensity, duration and type of exercise; the environment in which it is performed; whether it is an individual event or a team effort; and the number and frequency of times that the athlete must perform to decide the eventual winner. Despite the diversity of features, competition involves a common theme: athletes desire to perform at their best. Therefore, the starting point is to understand the factors that will cause the athlete to fatigue or experience a downturn in their performance.

3.3.1 Limitations to Performance during Competition

At some point during most sporting events, athletes experience deterioration in exercise outputs such as speed, power output, time spent in high-intensity activities or skill and concentration. This failure to maintain a desired or optimal exercise level is commonly termed fatigue, and may occur intermittently throughout the event, but particularly towards the end. Typically, success in competitive events is achieved by reducing or delaying the onset of such fatigue.

There are a variety of ways in which fatigue can occur during a sports competition, with nutrition playing a role in many of these (see Table 3.6). Their risk of occurrence depends on factors such as the duration and intensity of the event; environmental conditions (e.g. temperature and humidity); an athlete's training status and individual characteristics; and the opportunity to undertake nutrition strategies before, during and in the recovery between events. Whatever the sport or event, sports scientists try to pinpoint the likely risk that various factors will cause fatigue, based on the available

TABLE 3.6
Factors Related to Nutrition That Could Produce Fatigue or Suboptimal Performance during Sports Competition

Factor	Description	Examples of High Risk/Common Occurrence in Sports	Nutritional Strategies to Address Issue
Dehydration	Failure to drink enough fluid to replace sweat losses during an event. May be exacerbated if the athlete begins the event in fluid deficit.	Events undertaken in hot conditions, particularly for athletes with high-intensity activity patterns and/or heavy protective garments. Repeated competitions (e.g. tournaments) may increase risk of compounding dehydration from one event to the next. *Risk in para-sports*: It is difficult for some athletes to obtain and consume fluids during some competitions due to logistical issues and bathroom limitations.	The athlete should try to drink sufficient fluid in the period before the event so that they start well hydrated. Drinking during the event should track sweat rates to prevent a large fluid deficit from occurring.
Muscle glycogen depletion	Depletion of important muscle fuel due to high utilisation in a single event and/or poor recovery of stores from previous activity/event. Generally thought to occur in events longer than 90 min.	Generally occurs in events lasting longer than 90 min such as marathon, road cycling and Ironman triathlons. May occur in some team sports in "running" players with large total distances covered at high intensities (e.g. midfield players in football). Repeated competitions (e.g. tournament) may increase risk of poor refuelling from one match to the next. *Risk in para-sports*: Sports dependent on fewer muscle groups (e.g. arms) with smaller glycogen stores may deplete muscle glycogen earlier than 90 min and may benefit from loading (e.g. wheelchair marathon, hand cycling road race) or prioritisation of carbohydrate intake between events (team sport tournaments).	Carbohydrate loading – achieved by tapering exercise and eating a high-carbohydrate diet (10 g/kg BM/d) for 24–48 hours can supercompensate muscle glycogen stores and prolong the time before they become depleted. The total amount of carbohydrate may need to be reduced in para-sports due to smaller muscle size/energy budgets.

(*Continued*)

TABLE 3.6 (*Continued*)
Factors Related to Nutrition That Could Produce Fatigue or Suboptimal Performance during Sports Competition

Factor	Description	Examples of High Risk/Common Occurrence in Sports	Nutritional Strategies to Address Issue
Hypoglycaemia and depletion of central nervous system fuels	Reduction in blood glucose concentrations due to poor carbohydrate availability. Note that some athletes do not experience fatigue even when blood glucose concentrations become low.	Depletion of blood glucose may occur in athletes with high carbohydrate requirements (see above) who fail to consume carbohydrate during their event. *Risk in para-sports*: Team sport tournaments where more than one game is played per day.	Intake of carbohydrate during an event will prevent hypoglycaemia and provide fuel for the central nervous system.
	New research shows that even when the central nervous system is not depleted, the intake of carbohydrate can promote a "happy brain" that will allow the muscles to work at a higher power output.	Events of 45–75 min duration may benefit from carbohydrate intake to promote a "happy brain." *Risk in para-sports*: Some skill-based athletes (e.g. shooting, archery) will avoid fluid and food prior to competition to help control heart rate, avoid the need to use bathroom facilities and for gut comfort.	In shorter events, even tasting carbohydrate can promote a brain response. Regular tasting or intake of carbohydrate during the event enhances brain activity, leading to better performance.
Disturbance of muscle acid-base balance	High rates of hydrogen ion production via anaerobic glycolytic power system.	Prolonged high-intensity activities lasting 1–8 min (e.g. rowing events, middle distance running, 200–800 m swimming, track cycling team pursuit). May also occur in events with repeated sustained periods of high intensity activity – perhaps in some team games, racquet sports. *Risk in para-sports*: Athletes with an impairment compete in many events listed above.	An increase in extracellular (plasma) buffering capacity can be achieved via acute loading with sodium bicarbonate (300 mg/kg), 90–120 min prior to an event. Increase in the stores of intracellular buffer carnosine can be achieved by chronic (6–14 w) supplementation with β-alanine. Dosing protocols may require modification in Para athletes with special consideration of potential side effects.

(*Continued*)

TABLE 3.6 (*Continued*)
Factors Related to Nutrition That Could Produce Fatigue or Suboptimal Performance during Sports Competition

Factor	Description	Examples of High Risk/Common Occurrence in Sports	Nutritional Strategies to Address Issue
Depletion of phosphocreatine stores	Inadequate recovery of phosphocreatine system of power production, leading to gradual decline in power output in subsequent efforts.	Occurs in events with repeated efforts of high-intensity activity with short recovery internals – perhaps in some team games, racquet sports. *Risk in para-sports*: May be a factor in wheelchair basketball, tennis and rugby; badminton, sit volleyball.	Creatine supplementation (loading with 5 d @ 20–30 g/d and maintenance with 3–5 g/d) can increase muscle phosphocreatine content and enhance recovery from repeated high-intensity sprints.
Gastrointestinal disturbances	GI disturbances, including vomiting and diarrhoea, may directly reduce performance as well as interfere with nutritional strategies aimed at managing fluid and fuel status.	Poorly chosen intake of food and fluid before and/or during event. Risks included consuming a large amount of fat or fibre in pre-event meal, consuming excessive amounts of single carbohydrates during the event or becoming significantly dehydrated. *Risk in para-sports*: Many athletes with an impairment have gut problems which are exacerbated by exercise. Tight positioning in wheelchairs can also increase the risk of gastrointestinal disturbance.	The athlete should seek expert advice to identify the foods or eating practises which cause gut disturbances. Intake of food and fluids before and during events should be chosen, based on practise, to minimise these disturbances.
Salt depletion (?)	Inadequate replacement of sodium lost in sweat. There is anecdotal evidence that salt depletion may increase the risk of a specific type of whole-body muscle cramp.	Salty sweaters – individuals with high sweat rates and high sweat sodium concentrations who may acutely or chronically deplete exchangeable sodium pools *Risk in para-sports*: Athletes with cystic fibrosis.	This is a controversial area. While most cramps are caused by local muscle fatigue, there anecdotal evidence that a subset of cramps occurs in salty sweaters and is reduced by appropriate salt replacement during and after exercise.

(*Continued*)

TABLE 3.6 (*Continued*)
Factors Related to Nutrition That Could Produce Fatigue or Suboptimal Performance during Sports Competition

Factor	Description	Examples of High Risk/Common Occurrence in Sports	Nutritional Strategies to Address Issue
Water intoxication/ Hyponatremia (low blood sodium)	Excessive intake of fluids can lead to hyponatremia, ranging from mild (often asymptomatic) to severe (can be fatal). While this problem is more of a medical concern rather than a cause of fatigue, symptoms can include headache and disorientation, which can be mistaken as signs of dehydration.	Athletes with low sweat losses (e.g. low-intensity exercise in cool weather) who overzealously consume fluid before and during the event. This has most often been seen during marathons, ultra-endurance sports and hiking. *Risk in para-sports*: Athletes with spinal cord injuries may have low sweat losses yet perceive the need to drink due to heat load. Some intellectually impaired athletes my lack the understanding required to manage fluid intake effectively.	Practise in training will identify a fluid plan that does not allow the athlete to drink excessively during their event.

Source: Adapted from Burke, L.M. 2011. In: *Sport and Exercise Nutrition*. eds. Lanham-New, S.A. et al. pp. 200–209. London: Wiley-Blackwell.

applied sports research, as well as accounts of the past competition experiences of the athletes involved. With this knowledge, athletes can then be guided to undertake specific competition nutrition strategies that will minimise or delay the onset of these problems.

The range of competition strategies available to athletes to combat such fatigue factors includes practises of fluid and food intake before, during and in the interval between events, as well as the acute or chronic use of supplements with ergogenic effects such as caffeine, creatine, nitrate/beetroot juice and the buffering agents (i.e. extracellular buffering with bicarbonate supplementation, intracellular cellular buffering via beta-alanine supplementation). The role of performance supplements is covered in other areas of this text (see Chapter 14) and in other resources (Burke and Cato 2015, Peeling et al. 2018). Meanwhile, many of the following dietary strategies which form the basis of competition eating should also be integrated into some training sessions. This will allow the athlete to experiment with, and fine-tune, a personalised competition plan, including learning the habits or developing the gastrointestinal tolerance needed to carry it out successfully. These strategies may also help to support training sessions.

3.3.2 Precompetition Fuelling

An important goal of precompetition eating is to store sufficient muscle glycogen to meet the anticipated fuel needs of the event. Training typically enhances the muscle's capacity for glycogen storage such that the elevated "resting" values seen in endurance athletes are generally sufficient to meet the needs of events of <90 min duration (Hawley et al. 1997). Unless there is muscle damage, the athlete should be able to achieve such levels with as little as a day of a carbohydrate-rich diet in combination with rest or light training (Bussau et al. 2002). The amount of dietary carbohydrate targets needed to restore glycogen will vary according to the level of depletion, but somewhere in the range of 5–10 g per kg of the athlete's body mass will generally be sufficient to normalise muscle glycogen content (Burke et al. 2017b).

The fuel demands of some events, such as an ultra-endurance "Ironman" triathlon, are greater than the muscle's normal glycogen stores. Muscle glycogen depletion, causing a fatigue commonly known as "hitting the wall," can occur during events of greater than ~90 min duration in able-bodied athletes (potentially less during in Para athletes using smaller muscle groups), both of continuous or intermittent high-intensity nature. In such events, athletes should try to "carbohydrate load" or super-compensate glycogen stores prior to competition. Although the first protocols involved a week to implement via separate phases of glycogen depletion, then supercompensation (Bergstrom et al. 1967), more recent work has shown that a well-trained athlete can achieve the same outcomes simply by combining as little as 24–36 h of high carbohydrate intake and rest/exercise taper (Bussau et al. 2002). Therefore, the modern version of carbohydrate loading is a practical option for a large range of athletes who compete in fuel-demanding events. While some athletes may simply have to taper their training volume to allow glycogen to store, others may need to increase their intake of carbohydrate-rich foods and drinks above habitual levels to achieve the targets provided in Table 3.3. In addition, some athletes like to combine carbohydrate loading with a low-residue/low-fibre dietary plan that reduces gastrointestinal contents over the day(s) before competition (Burke 2015a). This provides the advantage of reducing body mass by 0.5–2 kg (providing a small but useful advantage in sports where the athlete carries their own body mass over distances) or removing the likelihood for a bowel movement on the day of the event (sometimes impractical in the field of play).

A practical consideration in competition preparation is the effect and the environment of the competition taper. In many sports, the achievement of a competition peak is preceded by a distinct training taper in which the volume of training is dramatically reduced for a period of 1–3 weeks. This reduces the athlete's energy expenditure, but ironically, also increases their amount of leisure time which encourages "boredom eating." Energy intake can also be mismatched during this period because of the food environment frequently encountered in the competition phase. Athletes who travel away from home and dietary supervision are frequently exposed to "all you can eat" catering in athlete villages or hotels. Unless the athlete is sufficiently knowledgeable and committed, it can be easy to overeat. On the other hand, many athletes find themselves in a location or with a catering plan that fails to provide them with their usual or important foods and drinks or without access to snacks between meals. This may interfere with their ability to consume sufficient energy and nutrients, or to cater to their special competition or recovery eating plans. Athletes should think ahead to bring their special food needs on their travels (customs regulations allowing) and to adapt their eating habits to their real needs rather than opportunities to eat.

3.3.3 The Pre-Event Meal

Foods and drinks consumed in the 4 h before an event have a role in fine-tuning competition preparation in meeting the following goals (Burke 2015a):

- To enhance muscle glycogen stores if they have not been fully restored or loaded since the last exercise session – this is often an issue in sports where the athlete competes in heats and finals, or several matches in a tournament
- If events are undertaken in the morning, to restore liver glycogen stores (important for maintaining blood glucose concentrations) after an overnight fast
- To ensure that the athlete is well hydrated, especially where a fluid deficit is likely to occur during the event and/or the athlete may be dehydrated from a hot environment or previous exercise
- To achieve gut comfort throughout the event, neither letting the athlete become hungry nor suffer gastrointestinal distress or upset, and
- To include foods and eating practises that are important to the athlete's psychology or superstition

There is no single routine that will suit the array of events, environments, timetables and food options in which competition is undertaken or the individual preferences of each athlete. Instead, each athlete should develop a personalised eating plan, guided by their specific circumstances, preferences and past experiences. Some general principles include the consumption of substantial amounts of carbohydrate-rich foods or drinks prior to endurance events (Sherman et al. 1989) and the avoidance of large amounts of fibre or fat by athletes who are at risk of gut problems. Pre-event hydration should involve drinking a comfortable amount of fluid sufficiently ahead of the event so that there is time for the urination of excess fluids. Athletes who suffer from pre-event nerves or undertake events scheduled in the early morning, where it is difficult to eat a substantial amount of food beforehand, often find it useful to choose a liquid version of the pre-event meal such as specially formulated liquid meal replacement products or milk/fruit smoothies. For some athletes, such as wheelchair racers who fit very compactly into their chairs, it is physically difficult to consume a large volume of food/fluid within 2–3 h of an event, hence very compact but easily digestible forms of fuel (such as gels) may be most useful.

Special attention has been focused on the possible disadvantages of consuming carbohydrate in the hours prior to exercise. Although pre-event intake of carbohydrate can enhance body carbohydrate stores, it also increases the rate at which carbohydrate is utilised as a fuel during subsequent exercise due to alterations in prevailing hormone (i.e. insulin) concentrations (Coyle et al. 1985). Early sports nutrition guidelines warned against the intake of carbohydrate in the hour before exercise in case the increased rates of carbohydrate utilisation impaired performance via a rebound hypoglycaemia or an earlier depletion of muscle glycogen stores (Foster et al. 1979). This may be the case for some individual athletes, especially in situations where the amount of carbohydrate consumed pre-event is small and unable to counter the increase in exercise carbohydrate use (Kuipers et al. 1999). However, in the majority of cases, the risk of a detrimental effect on performance is low, and in fact, performance is unaltered or enhanced by the additional carbohydrate availability (Jeukendrup and Killer 2010).

Several options are possible to minimise the potential problems associated with pre-exercise carbohydrate intake: these include consuming adequate carbohydrate (>1 g per kg BM) to offset the increased reliance on carbohydrate fuel use and choosing carbohydrate-rich sources that are low in glycaemic index (Burke 2015a). Indeed, low-glycaemic-index carbohydrate-rich foods have been promoted as a superior choice for the pre-event meal, offering a source of sustained release carbohydrate with less perturbation to the hormonal environment (Thomas et al. 1991). This may provide a benefit for particular scenarios or individuals, but outcomes of superior endurance compared with the intake of high-GI carbohydrate choices (Thomas et al. 1991) have not been found to be universal (Burke 2015a). Of course, the most effective strategy to maintain carbohydrate availability during the event is to continue to consume it throughout exercise; this offers a number of benefits to the muscle and central nervous system that will be subsequently discussed.

3.3.4 Fluid Intake during Exercise

In events lasting longer than ~45 minutes there may be opportunities and advantages to consuming fuel and fluids during the session. Sweat is lost during exercise as a means to dissipate the heat generated by muscular work or absorbed from the environment, and when it can be evaporated it provides an effective strategy to maintain body temperature within its homeostatic range. As the resulting fluid deficit increases, however, it gradually increases the stress associated with exercise. Typically, it is noted that when dehydration increases above 2%–3% BM, there is an increasing effect on work rates and skills during prolonged exercise (for review, see Burke 2019). Critics of this view (Cotter et al. 2014, Dugas et al. 2009) argue that it is almost entirely based on laboratory studies which can't incorporate the cooling effects of wind and air resistance or the motivating effects of the competition atmosphere. Furthermore, most studies of hydration have failed to blind the intake of fluids, thus adding the potential placebo effect. Therefore, the presently available studies might overestimate the true effect of dehydration on performance in real-life conditions.

A counterargument is that the statistical interpretation of most studies is weighted against finding small but potentially important effects of dehydration on performance. Combining probability statistics with small sample sizes generally means that sports research is only capable of detecting substantial reductions or differences in performance (Hopkins et al. 1999). Such analyses may fail to recognise performance changes that would affect the outcomes of real-life sport, where events are decided by milliseconds and millimetres. Furthermore, studies in which fluid intake and hydration status are "placebo controlled" (by being introduced by nasogastric tube, and providing equivalent small amounts of fluid for oropharyngeal stimulation in all trials) are beginning to appear, with some showing the benefits of better hydration status (Adams et al. 2018). Indeed, in studies where the same exercise is undertaken in a hot environment with incrementally increasing fluid deficits from 0% to 4% body mass, there is a parallel increase in thermoregulatory strain, cardiovascular drift and perception of effort (Montain and Coyle 1992). Intuitively, a similar subtle decrease in performance and/or increase in the effort required to perform is also happening, but we find it hard to draw the line in the sand where we consider it important. Indeed, the point at which this becomes noticeable or significant will depend on the individual, the environment (effects are greater in the heat or at altitude) and perhaps the focus of the exercise (recreational exercisers may stop exercising if it becomes uncomfortable; elite athletes may be prepared to tolerate greater discomfort but, equally, may have a greater incentive to perform well given the small margins between winning and losing).

Many of the expert guidelines on fluid intake in sport, such as the 2007 position stand of the American College of Sports Medicine, have attracted harsh criticism and counterarguments that humans need only drink fluids "to thirst" or "ad libitum" during exercise/sporting activities, rather than receive specific advice. It is clear that there is the potential for some athletes to overhydrate if they drink excessively during events in which sweat rates are low. Risk factors for this situation include being female, being small, exercising at low intensities (Almond et al. 2005) and having a spinal cord injury (see Chapter 6). This situation is generally unnecessary and may even be dangerous if it leads to the potentially fatal condition of hyponatremia (low blood sodium concentration, often known as water intoxication; Hew-Butler et al. 2008). However, a personalised hydration plan can assist both in the prevention of overhydration as well as achieving an organised rather than ad hoc approach to race/

event nutrition. Furthermore, it acknowledges that some of the factors that control opportunities for fluid intake during competitive sport are beyond the athlete's control and not always aligned to their thirst. Studies of hydration characteristics of sporting events typically show that fluid mismatches err on the side of a fluid deficit, especially during elite competition, which the athlete may then judge as either being tolerable or needing to be better addressed within the practicalities of the specific sport (Garth and Burke 2013).

Good drink choices will depend on the sport and on other nutritional goals that might be important. First, a fluid needs to be palatable and available to encourage intake. However other characteristics include temperature (Burdon et al. 2010, 2012), which can be manipulated both to enhance palatability in the specific environment and to contribute to body temperature regulation (cold fluids and ice slurries can reduce core temperature in hot conditions, while warm fluids may increase body temperature losses in cold environments). Second, there is the opportunity for a drink to contain other nutrients that might enhance performance, such as carbohydrate (Jeukendrup 2010; Jeukendrup and Chambers 2010) or caffeine (Burke 2008). Sports drinks which are formulated to meet a range of needs provide carbohydrate and electrolytes, with the latter encouraging fluid intake by maintaining thirst.

In general, it is suggested that athletes develop a personalised hydration plan that utilises the opportunities that are specific to their event to keep the fluid deficit below 2% of body mass in thermally stressful environments, or where this is not possible, to replace as much of their sweat loss as is practical. Table 3.7 summarises the main issues with fluid intake across a range of sports. Depending on the event, there may be opportunities to drink during breaks in play (i.e. half time, substitutions or time-outs in team games) or during the exercise itself (from aid stations, handlers or self-carried supplies). As discussed in Chapter 5, athletes can get a feel for their typical sweat losses during an event by conducting periodic checks of hydration during training sessions or events as is practical.

3.3.5 Fuel Intake during Competition

The muscle and central nervous system can both benefit from the intake of carbohydrate during exercise (Karelis et al. 2010). A range of mechanisms is possible, including providing a source of substrate to the muscle (Coyle et al. 1986) and enhancing the reward centres of the central nervous system (Chambers et al. 2009); these may occur singly or in combination according to the intensity and duration of the event and the athlete's nutritional preparation. Until recently, guidelines for the intake of carbohydrate during exercise stated that it would only be valuable during events longer than 1 hour in duration and recommended an intake of 30–60 g per hour, fine-tuned with individual experience (ACSM et al. 2007). Again, the specific characteristics of a sport such as the scheduling of breaks, competition rules, logistics and culture will determine the opportunities for consuming a sports drink or other carbohydrate-containing sources such as gels, bars or confectionery during the event (see Table 3.7). Some new research, however, has suggested ways in which fuelling guidelines need to be updated for shorter sustained intensity events and for longer or ultra-endurance sports.

TABLE 3.7
Summary of Key Issues Involved in Developing Individual Hydration and Fuelling Plans for Various Types of Sporting Activities

Type of Sports	Key Issues to Consider in Devising Specific Plan for Competition Fluid/Fuel Replacement
Continuous endurance events (e.g. distance running, wheelchair marathon, road cycling, Paratriathlon)	• Fluids and foods must be consumed during the race while athlete is "on the move." • *Access* to supplies is enhanced in events where drinks are provided by aid stations or handlers. • *Access* to drinks/foods is reduced in events where athlete must carry their own supplies. • *Opportunity* to drink/eat is limited by consideration of the time lost in obtaining and consuming fluid. • *Opportunity* to drink/eat is limited by gastro-intestinal discomfort associated with drinking while exercising. • Ability to consume fluid/foods during races may be enhanced by practising during training to develop gastrointestinal tolerance and the skills that allow drinking on the move. • Creative devices such as fluid backpacks and spillproof bottles may enhance access to fluid and the ease of drinking on the move. *Special issues regarding para-sports*: It is less easy to obtain and consume drinks in wheelchair or arm-cranked activities since the arms are needed for propulsion. Cerebral palsy and some other impairments may reduce fine motor control, increasing the likelihood of spillage/difficulty opening and handling vessels.
Team and racquet sports (rugby, tennis, basketball, badminton, sit volleyball, goalball, football, sled hockey)	• Fluids/foods can be consumed during breaks in game or pauses in play that are specific to the sport (e.g. timeouts, change of ends, half-time, substitutions). • *Opportunities* to drink/eat are increased in sports in which there are a number of formal and informal breaks, and where there is free player rotation. • *Access* to fluid is increased by having a team drink supply close to the field of play and, where rules permit, having trainers take drinks to players. • *Access* to fluid is reduced in sports in which rules prevent carriage of fluid onto field of play. • In some team sports there is a culture that dehydration during training can "toughen" players. • Individual drink bottles may enhance hydration practises by increasing awareness of total fluid intake. *Special issues regarding para-sports*: In spinal cord injuries, the heat load induced by the inability to sweat effectively can drive a greater fluid intake than needed. The need to cool athletes may outweigh their need to hydrate.

(*Continued*)

TABLE 3.7 (*Continued*)
Summary of Key Issues Involved in Developing Individual Hydration and Fuelling Plans for Various Types of Sporting Activities

Type of Sports	Key Issues to Consider in Devising Specific Plan for Competition Fluid/Fuel Replacement
Sprint, strength and power events – brief high-intensity sports - (e.g. track and field events, track cycling)	• No need or opportunity to hydrate/fuel during brief events, but athletes may need to rehydrate/refuel between events, especially in multiple event competition. *Special issues regarding para-sports*: Gastrointestinal comfort may be impacted by body positioning (e.g., wheelchair athletes) which influences pre-event/training food and fluid intake.
Weight-making sports (Judo, powerlifting, taekwondo)	• Education is needed to minimise reliance on dehydration to make weight for competition. • Weight-making practises may also involve poor fuelling in the days leading into the event. • Depending on the rules of the competition, the recovery period between weigh-in and competition vary from an hour to a day. Aggressive refuelling and rehydration may be needed, but caution may be needed to reduce risk of gut upsets during the event. *Special issues regarding para-sports*: The nature of some impairments can make it more difficult to use traditional techniques (such as dehydration) to reduce body mass acutely, meaning a smaller margin between training and competition weight is necessary.
Skill sports (shooting, archery, boccia, curling)	*Access* to fluid is reduced when sessions are undertaken in a remote environment.
Aquatic sports (swimming)	• Fluid needs are likely to be lower than equivalent "land-based" sports activities due to opportunity to dissipate heat through convection/conduction in water rather than sweating. • Drink bottles on pool deck are suitable.
Winter sports (Alpine and Nordic skiing, snowboarding)	• *Access* to fluid and food is reduced when session is undertaken in remote environment or subzero temperatures (food and drinks freeze). • Fluid needs (sweat losses) altered by cold environment or altitude, but thirst may be impacted more; hence, there is still a risk of dehydration. • Voluntary fluid intake may be enhanced by provision of warm fluids. *Special issues regarding para-sports*: In addition to reduced access to food and fluid, the impracticality of removing tight ski suits and more limited mobility also means reduced access to bathroom facilities, increasing the likelihood of limiting fluid and food intake before and during training/competition.

Source: Adapted from Garth, A.K. and Burke, L.M. 2013. *Sports Medicine* 43:539–564.

In longer events such as Ironman triathlons or stage races in road cycling, it has been curious to observe that top athletes self-select carbohydrate intakes that are much higher than recommended by sports nutrition guidelines – often around 80–90 g per hour (Kimber et al. 2002). This poses the question of who is wrong – the guidelines or the athletes? The answer has been answered in several ways. The first piece of information is emerging evidence of a dose response relationship between carbohydrate intake and performance of sports lasting 3 or more hours – in other words, the greater the carbohydrate dose, the better the performance, up to a point (Smith et al. 2013). The limiting factor to the supply of exogenous carbohydrate to the muscle is the amount of carbohydrate that can be absorbed from the gut. However, this can be enhanced if the athlete consumes a blend of different types of carbohydrates that are transported across the intestine in different ways; the maximum absorption of glucose appears to be about 60 g/h, but if a blend of glucose and fructose is consumed, it can be increased to 90 g/h (Jeukendrup 2010). Thus, the new guidelines continue to recommend intakes of 30–60 g/h in endurance events of 1–3 h, but for longer events, intake of up to 80–90 g/h are likely to contribute to the special fuel needs (Thomas et al. 2016). It appears also that the gut can be "trained" to increase its absorption rates of carbohydrate by regularly training with carbohydrate intake (Cox et al. 2010, Jeukendrup 2017b).

The new insight into carbohydrate intake during events of intermittent or sustained high-intensity lasting ~1 h is just as intriguing. In such events, muscle glycogen stores are adequate for fuel needs, so theoretically there should be no advantage to consuming carbohydrate during the event. Yet early studies involving cycling or running time trials recorded benefits from intake of carbohydrate just before and during exercise (Below et al. 1995, Jeukendrup et al. 1997), even if the carbohydrate was simply swilled around the mouth and spat out (Carter et al. 2004). There is now evidence that receptors in the mouth sense the presence of carbohydrate, allowing the reward centres in the brain to feel energised and pace at a higher level (Chambers et al. 2009). Meta-analyses and reviews of a now mature literature (Burke and Maughan 2015, Jeukendrup and Chambers 2010) provide robust support for the benefits of repeated and lingering exposure (~5–10 s) of carbohydrate within the mouth and oral cavity during a range of high-intensity events of ~ 1 h duration. Thus, new guidelines consider the benefits of consuming or tasting even a small amount of carbohydrate at regular intervals throughout shorter events, offering opportunities for sports nutrition practise across a new range of sports (Thomas et al. 2016).

3.3.6 Recovery between Events

In many sports, competition involves a series of events or matches before the final winner is decided, and the athlete will need to recover as quickly or as effectively as possible for the next round. The period between events may be less than an hour (e.g. races in a swimming program or track meet), 3–4 hours (e.g. singles and doubles matches on the same day of a tennis tournament) or 1–2 days (e.g. team sports in a tournament format). The principles of eating to promote rehydration, refuelling, repair and adaptation, covered in the previous section on training nutrition, may be more challenging to achieving in the competition environment due to issues such as poor access to food supplies or interference from postevent activities such as drug testing, media commitments and performance debriefs. With good planning, however, the athlete should aim to recover as well as possible – or at least better than his or her competitors.

3.4 SUMMARY

Research over the past three decades has produced a large amount of information that can now be shaped at an individualised level to maximise adaptations to chronic exercise (i.e. training) and to optimise performance on a specific occasion (i.e. competition). The evolution of the science and practise of sports nutrition now allows athletes to develop specific eating practises for the demands of their sport to achieve a suitable physique, to reduce the risk of illness and injury and to support the demands of training and recovery. In the competition arena, well-practised nutrition strategies undertaken before, during and in the interval between events can contribute to personal best performances. Although the demands of Para sports may be unique, most of the principles of sports nutrition that have been developed from studies of able-bodied athletes also apply to these special populations. The remainder of this book will endeavour to further investigate the application of sports nutrition to the specialised needs of Para athletes.

COMMENTARY BOX 3.3

ATHLETE INSIGHT: Over the years that you've been an athlete, has sports nutrition advice changed and if so, in what way?

> I'm not sure the advice has changed, but how I use the advice certainly has as I've become a more veteran athlete. I know for me, having a relationship with my nutritionist has helped me the most, even more important than the advice. Nutrition plans for Para athletes have to be so tailored to their level of impairment, in addition to the training/competing needs of each athlete. Building that friendship and trust with my nutritionist is what has changed for me over the last few years.

Steve Serio, Wheelchair Basketball, 3 time Paralympian (Beijing, London – Bronze medal and Rio – Gold medal)

SPECIAL COMMENTARY: WEIGHT CATEGORY SPORTS

At the Paralympic level, there are three weight category sports in which athletes with an impairment can compete – powerlifting (for those whose lower limbs are most affected by their impairment), Taekwondo (in Tokyo, for athletes with upper or minor lower body limb loss) and judo (for vision impaired athletes only). At a nonelite level, athletes with an impairment may be involved in a wider range of weight-category sports.

Each weight-category sport has different rules regarding weigh-in requirements, including the time of weigh-in prior to competition. In para-sports, there may also be different rules applied and these may be modified for smaller competitions. For example, in powerlifting, where two lifters lift the same weight, their final ranking can be decided according to their actual body mass (i.e. the lighter of the two will be ranked higher). In smaller competitions where there are only 1–2 individuals per weight class, this ruling may be applied to rank all competitors regardless of their weight division. It is important for the practitioner to be aware of variations in rules in order to best support the athlete's body mass management.

Athletes in some weight-category sports compete regularly throughout the competition season, sometimes on a weekly basis. Therefore, they will be required to "make weight" repeatedly throughout this period of time. Other weight category sports only compete 3–4 times over a year due to more limited opportunities for competition. The key to consistent success in weight-category sports is achieving a sustainable weight early in the precompetition period, then minimising weight fluctuations throughout the competition period. There is a competitive advantage to training above competition weight (rather than AT competition weight) in most weight-category sports, since this allows for a taller and more muscular physique which can provide greater strength, power and leverage. By the same token, the closer an athlete is to their competition weight through the training period, the easier it will be to both make weight and effectively control body mass over a competitive season, minimising both the physical and psychological "stress" of making weight. The practitioner must work with the athlete and coach to determine what this training weight should be and how best to achieve it. The principles of body mass control in athletes with an impairment in weight-category sports are no different to those of able-bodied athletes; however, the means to achieve acute weight loss may be less effective or have greater impact on the health and performance of these athletes and so require extra care. The key principles, strategies and recommendations are summarised in Table C1.

There are a range of excellent resources available to guide sports nutrition practitioners working with weight-category sports, including:

O'Connor, H. and Slater, G. 2011. Losing, gaining and making weight for athletes. In: *Sport and Exercise Nutrition*. eds. Lanham-New, S.A., Stear, S.J., Shirreffs, S.M. and Collins, A.L. pp. 210–232. West Sussex: Wiley-Blackwell.

Walberg Rankin, J. and Gibson, J. 2015. Making weight. In: *Clinical Sports Nutrition* (5th edn). eds. Burke, L. and Deakin, V. pp. 191–212. Sydney: McGraw-Hill.

Reale, R., Slater, G. and Burke, L.M. 2017. Individualised dietary strategies for Olympic combat sports: Acute weight loss, recovery and competition nutrition. *European Journal of Sport Science* 17:727–740.

Reale, R., Slater, G. and Burke, L.M. 2017. Acute weight loss strategies for combat sports and applications to Olympic success. *International Journal of Sports Physiology and Performance* 12:142–151.

Reale, R., Slater, G., Cox, G.R., Dunican, I.C. and Burke, L.M. 2018. The effect of water loading on acute weight loss following fluid restriction in combat sports athletes. *International Journal of Sport Nutrition and Exercise Metabolism* May 3:1–9. doi: 10.1123/ijsnem.2017–0183. [Epub ahead of print]

TABLE C1
Body Composition Control in Weight-Category Sports

Outcome	Suggested Strategies	Considerations for Athletes with an Impairment
Setting a realistic weight category	• Assess body composition (DXA, surface anthropometry) in a hydrated state at start of training phase. • Set lowest possible weight category based on minimum % body fat of 5% (males) or 12% (females). • Allow for maximal weight loss of 1% body mass/week over training phase.	Accurate assessment of body composition via surface anthropometry may not be possible. Dual-energy x-ray absorptiometry (DXA) scans may not be easy to repeat frequently and hence may be best used in combination with another method. Total body fat % in some athletes is higher due to muscle atrophy and hence the "minimum % body fat" may require adjustment to a higher set point (e.g. SCI). Smaller weekly weight loss targets may be necessary. Consider impact of weight change on prostheses fitting. It may be better to set a higher weight category than what might be considered achievable.
Set preferred "training" weight	• Training weight (hydrated) should be no more than 5% above competition weight. • Goal is to achieve this in precompetition phase, then maintain throughout competition season. • Checks for hydration status can be useful to reinforce the importance of adequate hydration on health and performance.	If safe acute weight loss strategies are limited, training weight should be closer to competition weight.
Advise athlete regarding strategies to achieve chronic body mass loss progressively	• Energy restriction (~2000–4000 kJ/d or 500–1000 kcal/d). • Avoid low energy availability. • Optimise timing and distribution of fuel for training. • Adequate protein and even distribution over the day, with timing postexercise prioritised.	The degree of energy deficit should be proportional to current energy requirements, which may be lower (e.g. in spinal cord injured).

(*Continued*)

TABLE C1 (*Continued*)
Body Composition Control in Weight-Category Sports

Outcome	Suggested Strategies	Considerations for Athletes with an Impairment
Use "safe" acute weight-making strategies that can be recovered from in time to compete (ensure these are trialled in training)	• Small energy deficit (if not already in place). • 2–3 d low fibre/residue diet. • Salt restriction if habitually consume a high-sodium diet. • 24 h fluid restriction and/or sweat loss without fluid replacement (sauna, hot bath, light exercise) leading into weigh-in. • Consideration of "water loading" technique (higher water intake 3 days leading into 24 h fluid restriction) in experienced athletes.	Athletes who have very controlled bowel management programs will be more resistant to using a low fibre/residue diet. Sweat loss capability may be limited in some athletes. Dehydration can increase the risk of urinary tract infections, which some athletes are more prone to. Consideration of impact of high urine outputs necessary for water loading technique.
Recover between weigh-in and competition "bout"	• Rehydrate with fluid including electrolytes (150% of weight lost through fluid restriction). • Carbohydrate to restore blood glucose and liver glycogen.	Rapid rehydration requires good access to bathroom facilities and must be trialled in training period
Prevent weight "rebound" postcompetition	• Manage alcohol intake. • Control food volume and type.	

RECOMMENDED READINGS

Burke, L.M. and Cox, G. 2010. *The Complete Guide to Food for Sports Performance*. Sydney: Allen & Unwin.

Burke, L.M. and Deakin, V. 2015. *Clinical Sports Nutrition* (5th edn). Sydney: McGraw Hill.

Burke, L.M., Hawley, J.A., Jeukendrup, A., Morton, J.P., Stellingwerff, T. and Maughan, R.J. 2018. Toward a common understanding of diet-exercise strategies to manipulate fuel availability for training and competition preparation in endurance sport. *International Journal of Sports Nutrition and Exercise Metabolism* 28:451–463.

Halson, S.L., Burke, L.M. and Pearce, J. 2019. Nutrition for travel – from jetlag to catering. *International Journal of Sports Nutrition and Exercise Metabolism [epub ahead of print].*

Jeukendrup, A. and Gleeson, M. 2018. *Sport Nutrition* (3rd edn). Champaign: Human Kinetics.

Lanham-New, S.A., Stear, S.J., Shirreffs, S.M. and Collins, A.L. 2011. *Sport and Exercise Nutrition*. London: Wiley-Blackwell.

Maughan, R.J. and Burke, L.M. 2011. *Sports Nutrition: More than Just Calories – Triggers for Adaptation*. Nestle Nutrition Institute Workshop Series, Vol 69. Vevey: Nestec Ltd and Basel: S. Karger AG.

Thomas, D.T., Erdman, K.A. and Burke, L.M. 2016. American College of Sports Medicine Joint Position Statement. Nutrition and athletic performance. *Medicine and Science in Sports and Exercise* 48:543–568.

REFERENCES

Achten, J., Halson, S.L., Moseley, L., Rayson, M.P., Casey, A. and Jeukendrup, A.E. 2004. Higher dietary carbohydrate content during intensified running training results in better maintenance of performance and mood state. *Journal of Applied Physiology* 96:1331–1140.

Adams, J.D., Sekiguchi, Y., Suh, H.G. et al. 2018. Dehydration impairs cycling performance, independently of thirst: A blinded study. *Medicine and Science in Sports and Exercise* 50:1697–1703.

Ainsworth, B.E., Haskell, W.L., Hermann, S.D. et al. 2011. 2011 Compendium of physical activities: A second update of codes and MET values. *Medicine and Science in Sports and Exercise* 43:1577–1581.

Almond, C.S., Shin, A.Y., Fortescue, E.B. et al. 2005. Hyponatremia among runners in the Boston marathon. *New England Journal of Medicine* 352:1550–1556.

American College of Sports Medicine, Sawka, M.N., Burke, L.M. et al. 2007. American College of Sports Medicine Position Stand. Exercise and fluid replacement. *Medicine and Science in Sports and Exercise* 39:377–390.

Below, P.R., Mora-Rodriguez, R., Gonzalez-Alonso, J. and Coyle, E.F. 1995. Fluid and carbohydrate ingestion independently improve performance during 1 h of intense exercise. *Medicine and Science in Sports and Exercise* 27:200–210.

Bergstrom, J., Hermansen, L., Hultman, E. and Saltin, B. 1967. Diet, muscle glycogen and physical performance. *Acta Physiologica Scandinavica* 71:140–150.

Bermon, S., Castell, L.M., Calder, P.C. et al. 2017. Consensus statement: Immunonutrition and exercise. *Exercise Immunology Review* 23:8–50.

Betts, J.A. and Williams, C. 2010. Short-term recovery from prolonged exercise: Exploring the potential for protein ingestion to accentuate the benefits of carbohydrate supplements. *Sports Medicine* 40:941–959.

Bishop, N.C., Walker, G.J., Gleeson, M., Wallace, F.A. and Hewitt, C.R. 2009. Human T lymphocyte migration towards the supernatants of human rhinovirus infected airway epithelial cells: Influence of exercise and carbohydrate intake. *Exercise Immunology Review* 15:127–144.

Braun, W.A. and Von Duvillard, S.P. 2004. Influence of carbohydrate delivery on the immune response during exercise and recovery from exercise. *Nutrition* 20:645–650.

Broad, E.M., Dew, D., Newshome, L. and Barfield, A. Measured and predicted resting energy expenditure in wheelchair rugby athletes. *Journal of Spinal Cord Medicine* in review.

Burd, N.A., West, D.W., Moore, D.R. et al. 2011. Enhanced amino acid sensitivity of myofibrillar protein synthesis persists for up to 24 h after resistance exercise in young men. *Journal of Nutrition* 141:568–573.

Burdon, C.A., Johnson, N.A., Chapman, P.G. and O'Connor, H.T. 2012. Influence of beverage temperature on palatability and fluid ingestion during endurance exercise: A systematic review. *International Journal of Sport Nutrition and Exercise Metabolism* 22:199–211.

Burdon, C.A., O'Connor, H.T., Gifford, J.A. and Shirreffs, S.M. 2010. Influence of beverage temperature on exercise performance in the heat: A systematic review. *International Journal of Sport Nutrition and Exercise Metabolism* 20:166–174.

Burke, L. 2015a. Preparation for competition. In: *Clinical Sports Nutrition* (5th edn). eds. Burke, L., and Deakin, V. pp. 346–376. Sydney: McGraw-Hill.

Burke, L. and Cato, L. 2015. Supplements and sports foods. In: *Clinical Sports Nutrition* (5th edn). eds. Burke, L. and Deakin, V. pp. 493–591. Sydney: McGraw-Hill.

Burke, L.M. 2008. Caffeine and sports performance. *Applied Physiology Nutrition and Metabolism* 33:1319–1334.

Burke, L.M. 2011. Competition nutrition. In: *Sport and Exercise Nutrition*. eds. Lanham-New, S.A., Stear, S.J., Shirreffs, S.M. and Collins, A.L. pp. 200–209. London: Wiley-Blackwell.

Burke, L.M. 2015b. Re-examining high-fat diets for sports performance: Did we call the 'nail in the coffin' too soon?. *Sports Medicine* 15(Suppl 1):S33–49.

Burke, L.M. 2019. Hydration in sport. In: *Heat Stress in Sports and Exercise: Thermophysiology of Health and Performance*. eds. Periard, J. and Racinais, S. Springer (in press).

Burke, L.M., Hawley, J.A., Jeukendrup, A.E., Morton, J.P., Stellingwerff, T. and Maughan, R.J. 2018. Commentary: Towards a common understanding of diet-exercise strategies to manipulate fuel availability for training and competition preparation in endurance sport. *International Journal of Sport Nutrition and Exercise Metabolism* 28:451–463.

Burke, L.M. and Maughan, R.J. 2015. The governor has a sweet tooth - Mouth sensing of nutrients to enhance sports performance. *European Journal of Sport Science* 15:29–40.

Burke, L.M., Ross, M.L., Garvican-Lewis, L.A. et al. 2017a. Low carbohydrate, high fat diet impairs exercise economy and negates the performance benefit from intensified training in elite race walkers. *Journal of Physiology* 595:2785–2807.

Burke, L.M., van Loon, L.J.C. and Hawley, J.A. 2017b. Postexercise muscle glycogen resynthesis in humans. *Journal of Applied Physiology* 122:1055–1067.

Bussau, V.A., Fairchild, T.J., Rao, A., Steele, P.D. and Fournier P.A. 2002. Carbohydrate loading in human muscle: An improved 1 day protocol. *European Journal of Applied Physiology* 87:290–295.

Cannell, J.J., Hollis, B.W., Sorenson, M.B., Taft, T.N. and Anderson, J.J.B. 2009. Athletic performance and vitamin D. *Medicine and Science in Sports and Exercise* 41:1102–1110.

Carter, J.M., Jeukendrup, A.E. and Jones, D.A. 2004. The effect of carbohydrate mouth rinse on 1-h cycle time trial performance. *Medicine and Science in Sports and Exercise* 36:2107–2111.

Castell, L. 2003. Glutamine supplementation *in vitro* and *in vivo*, in exercise and in immunodepression. *Sports Medicine* 33:323–345.

Chambers, E.S., Bridge, M.W. and Jones, D.A. 2009. Carbohydrate sensing in the human mouth: Effects on exercise performance and brain activity. *The Journal of Physiology* 587:1779–1794.

Chowdhury, E.A., Western, M.J., Nightingale, T.E., Peacock, O.J. and Thompson, D. 2017. Assessment of laboratory and daily energy expenditure estimates from consumer multisensory physical activity monitors. *PLOS ONE* 12:e0171720.

Chun, S.M., Kim, H.R. and Shin, H.I. 2017. Estimating the Basal metabolic rate from fat free mass in individuals with motor complete spinal cord injury. *Spinal Cord* 55:844–847.

Clancy, R.L., Gleeson, M., Cox, A. et al. 2006. Reversal in fatigued athletes of a defect in interferon gamma secretion after administration of *Lactobacillus acidophilus*. *British Journal of Sports Medicine* 40:351–354.

Close, G.L., Ashton, T., Cable, T. et al. 2006. Ascorbic acid supplementation does not attenuate post-exercise muscle soreness following muscle-damaging exercise but may delay the recovery process. *British Journal of Nutrition* 95:976–981.

Collins, E.G., Gater, D., Kiratli, J., Butler, J., Hanson, K. and Langbein W.E. 2010. Energy cost of physical activities in persons with spinal cord injury. *Medicine and Science in Sports and Exercise* 42:691–700.

Conger, S.A. and Bassett, D.R. 2011. A compendium of energy costs of physical activities for individuals who use manual wheelchairs. *Adapted Physical Activity Quarterly* 28:310–325.

Cotter, J.D., Thornton, S.N., Lee, J.K. and Laursen, P.B. 2014. Are we being drowned in hydration advice? Thirsty for more? *Extreme Physiology and Medicine* 3:18. doi: 10.1186/2046-7648-3-18.

Cox, A.J., Pyne, D.B., Saunders, P.U. and Fricker, P.A. 2008. Oral administration of the probiotic *Lactobaccillus fermentum* VRI-003 and mucosal immunity in endurance athletes. *British Journal of Sports Medicine* 44:222–226.

Cox, G.R., Clark, S.A., Cox, A.J. et al. 2010. Daily training with high carbohydrate availability increases exogenous carbohydrate oxidation during endurance cycling. *Journal of Applied Physiology* 109:126–134.

Coyle, E.F. 1991. Timing and method of increased carbohydrate intake to cope with heavy training, competition and recovery. *Journal of Sports Sciences* 9(Suppl.):29–51.

Coyle, E.F., Coggan, A.R., Hemmert, M.K. and Ivy, J.L. 1986. Muscle glycogen utilisation during prolonged strenuous exercise when fed carbohydrate. *Journal of Applied Physiology* 61:165–172.

Coyle, E.F., Coggan, A.R., Hemmert, M.K., Lowe, R.C. and Walters, T.J. 1985. Substrate usage during prolonged exercise following a preexercise meal. *Journal of Applied Physiology* 59:429–433.

Cunningham, J.J. 1980. A reanalysis of the factors influencing basal metabolic rate in normal adults. *American Journal of Clinical Nutrition* 33:2372–2374.

Davis, J.M., Murphy, E.A. and Charmichael, M.D. 2009. Effects of the dietary flavonoid quercetin upon performance and health. *Current Sports Medicine Reports* 8:206–213.

Deakin, V., Kerr, D. and Boushey, C. 2015. Dietary assessment of athletes: Clinical and research perspectives. In: *Clinical Sports Nutrition* (5th edn). eds. Burke, L. and Deakin, V. pp. 27–54. Sydney: McGraw-Hill.

Deakin, V. and Peeling, P. 2015. Prevention, detection and treatment of iron depletion. In: *Clinical Sports Nutrition* (5th edn). eds. Burke, L. and Deakin, V. pp. 266–309. Sydney: McGraw-Hill.

Dugas, J. P., Oosthuizen, U., Tucker, R. and Noakes, T. D. 2009. Rates of fluid ingestion alter pacing but not thermoregulatory responses during prolonged exercise in hot and humid conditions with appropriate convective cooling. *European Journal of Applied Physiology* 105:69–80.

Edwards, T., Barfield, J.P., Neimiro, G.M. et al. 2018. Physiological responses during a 25-km time trial in elite wheelchair racing athletes. *Spinal Cord Series and Cases* 4:77.

Fischer, C.P., Hiscock, N.J., Penkowa, M. et al. 2004. Supplementation with vitamins C and E inhibits the release of interleukin-6 from contracting human skeletal muscle. *Journal of Physiology* 558:633–645.

Foster, C., Costill, D.L. and Fink, W.J. 1979. Effects of preexercise feedings on endurance performance. *Medicine and Science in Sports and Exercise* 11:1–5.

Garth, A.K. and Burke, L.M. 2013. What do athletes drink during competitive sporting activities? *Sports Medicine* 43:539–564.

Gejl, K.D., Thams, L.B., Hansen, M. et al. 2017. No superior adaptations to carbohydrate periodization in elite endurance athletes. *Medicine and Science in Sports and Exercise* 49:2486–2497.

Haakonssen, E.C., Ross, M.L., Knight, E.J. et al. 2015. The effects of a calcium-rich pre-exercise meal on biomarkers of calcium homeostasis in competitive female cyclists; a randomised crossover trial. *PLOS ONE* 10:e0123302.

Hansen, A.K., Fischer, C.P., Plomgaard, P., Andersen, J.L., Saltin, B. and Pedersen, B.K. 2005. Skeletal muscle adaptation: Training twice every second day vs. training once daily. *Journal of Applied Physiology* 98:93–99.

Harris, J.A. and Benedict, F.G. 1919. A biometric study of basal metabolism in man. *Journal of Chemical Information and Modeling* 4:370–373.

Havemann, L., West, S.J., Goedecke, J.H. et al. 2006. Fat adaptation followed by carbohydrate loading compromises high-intensity sprint performance. *Journal of Applied Physiology* 100:194–202.

Hawley, J.A., Schabort, E.J., Noakes, T.D. and Dennis, S.C. 1997. Carbohydrate-loading and exercise performance: an update. *Sports Medicine* 24:73–81.

Hearris, M.A., Hammond, K.M., Fell, J.M. and Morton, J.P. 2018. Regulation of muscle glycogen metabolism during exercise: Implications for endurance performance and training adaptations. *Nutrients* 10(3). doi: 10.3390/nu10030298.

Hemila, H. and Chalker, E. 2013. Vitamin C for preventing and treating the common cold. *Cochrane Database Systematic Reviews* Jan 31(1):CD000980. doi: 10.1002/14651858.CD000980.pub4.

Hew-Butler, T., Ayus, J.C., Kipps, C. et al. 2008. Statement of the second international exercise-associated hyponatremia consensus development conference, New Zealand, 2007. *Clinical Journal of Sport Medicine* 18:111–121.

Hopkins, W.G., Hawley, J.A. and Burke, L.M. 1999. Design and analysis of research on sport performance enhancement. *Medicine and Science in Sports and Exercise* 31:472–485.

Howell, A., Pruziner, A. and Andrews, A. 2015. Use of predictive energy expenditure equations in individuals with lower limb loss at seated rest. *Journal of the Academy of Nutrition and Dietetics* 115:1479–1485.

Impey, S.G., Hearris, M.A., Hammond, K.M. et al. 2018. Fuel for the work required: A theoretical framework for carbohydrate periodization and the glycogen threshold hypothesis. *Sports Medicine* 48:1031–1048.

Jeukendrup, A., Brouns, F., Wagenmakers, A.J.M. and Saris, W.H.M. 1997. Carbohydrate-electrolyte feedings improve 1 h time trial cycling performance. *International Journal of Sports Medicine* 18:125–129.

Jeukendrup, A.E. 2010. Carbohydrate and exercise performance: The role of multiple transportable carbohydrates. *Current Opinion in Clinical Nutrition and Metabolic Care* 13:452–457.

Jeukendrup, A.E. 2017a. Periodized nutrition for athletes. *Sports Medicine* 47(Suppl. 1):51–63.

Jeukendrup, A.E. 2017b. Training the gut for athletes. *Sports Medicine* 47(Suppl. 1):101–110.

Jeukendrup, A.E. and Chambers, E.S. 2010. Oral carbohydrate sensing and exercise performance. *Current Opinion in Clinical Nutrition and Metabolic Care* 13:447–451.

Jeukendrup, A.E. and Killer, S.C. 2010. The myths surrounding pre-exercise carbohydrate feeding. *Annals of Nutrition and Metabolism* 57(Suppl. 2):18–25.

Joaquim, D.P., Juzwiak, D.R. and Winckler, C. 2018. Do Paralympic track and field athletes have low energy availability?. *Revista Brasiliera de Cineantropometria e Desempenho Humano* 20:71–81.

Juzwiak, C.R., Winckler, C., Joaquim, D.P., da Silva, A. and de Mello, M.T. 2016. Comparison of measured and predictive values of basal metabolic rate in Brazilian Paralympic track and field athletes. *International Journal of Sport Nutrition and Exercise Metabolism* 26:330–337.

Karelis, A.D., Smith, J.W., Passe, D.H. and Péronnet, F. 2010. Carbohydrate administration and exercise performance: What are the potential mechanisms involved? *Sports Medicine* 40:747–763.

Kawamura, T. and Muraoka, I. 2018. Exercise-induced oxidative stress and the effects of antioxidant intake from a physiological viewpoint. *Antioxidants* 7:119.

Kimber, N.E., Ross, J.J., Mason, S.L. and Speedy, D.B. 2002. Energy balance during an Ironman triathlon in male and female triathletes. *International Journal of Sport Nutrition and Exercise Metabolism* 12:47–62.

Kuipers, H., Fransen, E.J. and Keizer, H.A. 1999. Pre-exercise ingestion of carbohydrate and transient hypoglycemia during exercise. *International Journal of Sports Medicine* 20:227–231.

Manore, M.M. and Thompson, J.L. 2015. Energy requirements of the athlete: Assessment and evidence of energy efficiency. In: *Clinical Sports Nutrition* (5th edn). eds. Burke, L. and Deakin, V. pp. 114–163. Sydney: McGraw-Hill.

Marquet, L.A., Brisswalter, J., Louis, J. et al. 2016. Enhanced endurance performance by periodization of carbohydrate intake: 'Sleep low' strategy. *Medicine and Science in Sports and Exercise* 48:663–672.

Maughan, R.J., Leiper, J.B. and Shirreffs, S.M. 1997. Factors influencing the restoration of fluid and electrolyte balance after exercise in the heat. *British Journal of Sports Medicine* 31:175–182.

Mifflin, M.D., St Jeor, S.T., Hill, L.A, Scott, B.J., Daugherty, S.A. and Koh, Y.O. 1990. A new predictive equation in healthy individuals for resting energy. *American Journal of Clinical Nutrition* 51:241–247.

Montain, S.J. and Coyle, E.F. 1992. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *Journal of Applied Physiology* 73:1340–1350.

Moore, D., Phillips, S. and Slater, G. 2015. Protein. In: *Clinical Sports Nutrition* (5th edn). eds. Burke, L. and Deakin, V. pp. 95–113. Sydney: McGraw-Hill.

Nightingale, T.E. and Gorgey, A.S. 2018. Predicting basal metabolic rate in men with motor complete spinal cord injury. *Medicine and Science in Sports and Exercise* 50:1305–1312.

Nightingale, T.E., Rouse, P.C., Thompson, D. and Bilzon, J.L.J. 2017. Measurement of physical activity and energy expenditure in wheelchair users: methods, considerations and future directions. *Sports Medicine – Open* 3:10.

Noakes, T., Volek, J.S. and Phinney, S.D. 2014. Low-carbohydrate diets for athletes: What evidence? *British Journal of Sports Medicine* 48:1077–1078.

Owen, O.E., Holup, J.L., D'Alessio, D.A. et al. 1987. A reappraisal of the caloric requirements of men. *American Journal of Clinical Nutrition* 46:75–85.

Owen, O.E., Kavle, E., Owen, R.S. et al. 1986. A reappraisal of caloric requirements in healthy women. *American Journal of Clinical Nutrition* 44:1–19.

Peeling, P., Binnie, M.J., Goods, P.S.R., Sim, M. and Burke, L.M. 2018. Evidence-based supplements for the enhancement of athletic performance. *International Journal of Sports Nutrition and Exercise Metabolism* 28:178–187.

Pelly, F.E., Broad, E.M., Stuart, N. and Holmes, M.A. 2018. Resting energy expenditure in male athletes with a spinal cord injury. *The Journal of Spinal Cord Medicine* 41:208–215.

Peters, E.M., Goetzsche, J.M., Grobbelaar, B. and Noakes, T.D. 1993. Vitamin C supplementation reduces the incidence of postrace symptoms of upper-respiratory-tract infection in ultramarathon runners. *American Journal of Clinical Nutrition* 57:170–174.

Phinney, S.D., Bistrian, B.R., Evans, W.J., Gervino, E. and Blackburn, G.L. 1983. The human metabolic response to chronic ketosis without caloric restrictions: Preservation of submaximal exercise capacity with reduced carbohydrate oxidation. *Metabolism* 32:769–776.

Res, P.T., Groen, B., Pennings, B. et al. 2012. Protein ingestion before sleep improves postexercise overnight recovery. *Medicine and Science in Sports and Exercise* 44:1560–1569.

Ristow, M., Zarse, K., Oberbach, A. et al. 2009. Antioxidants prevent health-promoting effects of physical exercise in humans. *Proceedings of the National Academy of Science USA* 106:8665–8670.

Rogalski, B., Dawson, B., Heasman, J. and Gabbett, T.J. 2013. Training and game loads and injury risk in elite Australian footballers. *Journal of Science and Medicine in Sport* 16:499–503.

Sanborn, C., Nichols, D.L. and DiMarco, N.M. 2011. Bone health. In: *Sport and Exercise Nutrition*. eds. Lanham-New, S.A., Stear, S.J., Shirreffs, S.M. and Collins, A.L. pp. 244–263. Oxford: Wiley-Blackwell.

Scaramella, J., Kirihennedige, N. and Broad, E. 2018. Key nutritional strategies to optimize performance in Para athletes. *Physical Medicine and Rehabilitation Clinics of North America* 29:283–298.

Scofield, K.L. and Hecht, S. 2012. Bone health in endurance athletes: Runners, cyclists and swimmers. *Current Sports Medicine Reports* 11:328–334.

Shephard, R.J. and Aoyagi, Y. 2012. Measurement of human energy expenditure, with particular reference to field studies: An historical perspective. *European Journal of Applied Physiology* 112:2785–2815.

Sherman, W.M., Brodowicz, G., Wright, D.A., Allen, W.K., Simonsen, J. and Dernbach, A. 1989. Effects of 4 h preexercise carbohydrate feedings on cycling performance. *Medicine and Science in Sports and Exercise* 21:598–604.

Sinnott-O'Connor, C., Comyns, T.M., Nevill, A.M. and Warrington, G.D. 2018. Salivary biomarkers and training load during training and competition in Paralympic swimmers. International Journal of Sports Physiology and Performance 13:839–843.

Slater, G., Pyne, D. and Tipton, K. 2015. Immunity, infective illness and injury. In: *Clinical Sports Nutrition* (5th edn). eds. Burke, L. and Deakin, V. pp. 730–755. Sydney: McGraw-Hill.

Smith, J.W., Pascoe, D.D., Passe, D.H. et al. 2013. Curvilinear dose-response relationship of carbohydrate (0–120 $g{\cdot}h^{-1}$) and performance. *Medicine and Science in Sports and Exercise* 45:336–341.

Somerville, V., Bringans, C. and Braakhuis, A. 2017. Polyphenols and performance: A systematic review and meta-analysis. *Sports Medicine* 47:1589–1599.

Stellingwerff, T. 2012. Case study: Nutrition and training periodization in three elite marathon runners. *International Journal of Sport Nutrition and Exercise Metabolism* 22:392–400.

Stellingwerff, T. 2018. Case study: Body composition periodization in an Olympic-level female middle-distance runner over a 9-year career. *International Journal of Sports Nutrition and Exercise Metabolism* 28:428–433.

Stellingwerff, T. and Cox, G.R. 2014. Systematic review: Carbohydrate supplementation on exercise performance or capacity of varying durations. *Applied Physiology, Nutrition and Metabolism* 39:998–1011.

Thomas, D.E., Brotherhood, J.R. and Brand, J.C. 1991. Carbohydrate feeding before exercise: Effect of glycemic index. *International Journal of Sports Medicine* 12:180–186.

Thomas, D.T., Erdman, K.A. and Burke, L.M. 2016. American College Of Sports Medicine Joint Position Statement. Nutrition and athletic performance. *Medicine and Science in Sports and Exercise* 48:543–68.

Thompson, J.L. and Manore, M.M. 1996. Predicted and measured resting metabolic rate of male and female endurance athletes. *Journal of the American Dietetic Association* 96:30–34.

Volek, J.S., Freidenreich, D.J., Saenz, C. et al. 2016. Metabolic characteristics of keto-adapted ultra-endurance runners. *Metabolism* 65:100–110.

Volek, J.S., Noakes, T. and Phinney, S.D. 2015. Rethinking fat as a fuel for endurance exercise. *European Journal of Sport Science* 15:13–20.

Walsh, N.P. 2018. Recommendations to maintain immune health in athletes. *European Journal of Sport Science* 18:820–831.

Walsh, N.P., Gleeson, M., Pyne, D.B. et al. 2011. Position statement. Part two: Maintaining immune health. *Exercise Immunology Review* 17:64–103.

West, N.P., Pyne, D.B., Cripps, A.W. et al. 2011. *Lactobaccillus fermentum* (PCC) supplementation and gastrointestinal and respiratory-tract illness symptoms: A randomised control trial in athletes. *Nutrition Journal* 10:30. doi: 10.1186/1475-2891-10-30.

Yeo, W.K., Paton, C., Garnham, A.P., Burke, L.M., Carey, A.L. and Hawley, J.A. 2008. Skeletal muscle adaptation and performance responses to once a day versus twice every second day endurance training regimens. *Journal of Applied Physiology* 105:1462–1470.

4 Energy Availability in Para Athletes

Claudia Ridel Juzwiak and Daniel Paduan Joaquim

CONTENTS

4.1 INTRODUCTION

It is fundamental to properly determine athletes' energy needs, since adequate energy supports health and specific training demands and reduces fatigue and the risk of injury (Thomas et al. 2016). When the energy supply is insufficient to cover energy expenditure, performance and health may be negatively affected. Although great advances have been made into understanding how an insufficient supply of energy affects health and performance, there are gaps that must be explored, such as how to best prevent it and what its long-term consequences are, especially in Para athletes (Mountjoy et al. 2018).

The current state of the art suggests that the best way to guarantee athletes' energy requirement is to determine their energy availability (EA) (Burke et al. 2006; Thomas et al. 2016). Insufficient EA is related to clinical alterations detrimental to health and performance. It has been associated with the female athlete triad (TRIAD), which involves energy availability, bone health and menstrual status (DeSouza et al. 2014), and in both male and female athletes with a syndrome called relative energy deficiency in sports (RED-S) (Mountjoy et al. 2018).

In this chapter, we provide an overview on the concept of energy availability, and its implications for athletes, especially Para athletes.

4.2 WHAT IS ENERGY AVAILABILITY?

Energy availability is defined as the amount of energy remaining for all normal physiological processes after the energy expended during exercise is taken into consideration. EA is calculated as:

EA = [Energy intake (EI) − Exercise energy expenditure (EEE)]/Fat Free Mass (FFM, kg).

Values ≥ 190 kJ/kgFFM/d (45 kcal/kgFFM/d) are considered adequate for able-bodied healthy athletes, while values <125 kJ/kgFFM/d (30 kcal/kgFFM/d) are considered low energy availability (LEA), indicating that the energy consumed is insufficient to support expenditure of both exercise and physiological functions (Logue et al. 2017; Loucks et al. 2011; Mountjoy et al. 2014). Values between 125 and 190 kJ/kg/FFM/d (30 and 45 kcal/kgFFM/d) can be considered reduced EA, indicating a tolerable energy intake, viable for short periods of time, aiming, for example, at reducing body mass (Muia et al. 2016).

The concept of EA has been proposed as an alternative to the estimation of energy requirements of athletes through the concept of energy balance (EB), which is traditionally used to establish athletes' energy requirements. EB is achieved when EI is equivalent to total energy expenditure, resulting in an energy balance of zero kJ/day (EB = 0 kJ/day) (Moreiras et al. 2015; Thomas et al. 2016).

EB is a dynamic process, and through manipulation of EI and/or EEE, it is possible to establish strategies to modify body mass and body composition, but it can also affect physiological processes in an unpredictable way (Manore et al. 2014; Moreiras et al. 2015). Stubbs et al. (2004) demonstrated this in an experiment conducted with eight untrained men evaluated by direct calorimetry for 1 week. Participants consumed (EI = 11590 kJ/d or 2770 kcal/d) and expended through exercise a constant daily amount of energy (EEE = 3515 kJ/d or 840 kcal/d), in a situation of constant low energy availability (125 kJ/kgFFM/d or 30 kcal/kgFFM/d). Throughout the experiment, there was a decrease in total energy expenditure on the magnitude of the negative EB (7238 kJ/d or 1730 kcal/d on day 1), at a rate of 377 kJ/d or 90 kcal/d. The authors suggested that individuals would have regained EB in 3 weeks at that rate, due to suppression in physiological processes, nevertheless maintaining the same condition of LEA. In this way, the use of the EB concept for athletes has been questioned, as it does not reliably express the relationship between the requirement and the energy supply for metabolic processes (Loucks et al. 2011).

The proposed cut-off point to determine LEA was based on the effects of energy intake on exercise stress, luteinising hormone (LH) levels and bone turnover markers in untrained women in a controlled environment. The determination of a cut-off point in a sports scenario is more complex due to the difficulty in measuring EA components accurately (Ihle and Loucks 2004; Loucks et al. 1998; Logue et al. 2017).

Determining energy requirements for Para athletes is even more challenging, primarily due to the lack of scientific data on a variety of impairments and exercise disciplines. Data on the prevalence of LEA for Para athletes is incomplete (Blauwet et al. 2017a; Mountjoy et al. 2018). However, the occurrence of energy inadequacies should not be overlooked in this population (Mountjoy et al. 2014), as they may have different demands due to their impairment (Blauwet et al. 2017a).

4.2.1 Low Energy Availability: Causes

Athletes achieve LEA unintentionally or by deliberately reducing food intake or increasing exercise expenditure. Insufficient energy consumption can be the result of a failure to adequately adjust energy intake to training load (lack of nutrition knowledge or exercise-induced appetite suppression), an inadequate program to lose body mass and/or body fat, or reasons unrelated to sports (i.e. aesthetics), as well as disordered eating or eating disorders (Koehler et al. 2013; Matzkin et al. 2015; Mountjoy et al. 2014).

In Para athletes, additional aspects have to be considered, such as some functional factors affecting energy expenditure (i.e. muscle spasms, gait) or focus on body mass management (i.e. wheelchair athletes to fit in sports chair; limb deficit and fit of prosthetics). Some Para athletes may have oral motor dysfunction, which causes difficulty in chewing and swallowing or presents substantial food aversions associated to new textures, and increased sensory sensitivity which may limit the variety and amount of food they are able to consume (Chapter 7; Broad and Juzwiak 2018).

COMMENTARY BOX 4.1

COACH’S COMMENTARY: For your particular athletes, what are the biggest nutrition challenges they face?

> Being appropriately organised with daily planning to ensure the nutrition plan is followed. Most of my athletes are either working or are full-time students, so are busy throughout the day in addition to their training sessions. Some of them fail to take the few minutes the night before or morning of to make certain they have their nutrition needs for the day ready, which then means most of their feeding takes place at the end of the day.

Adam Bleakney, Wheelchair T&F coach for over 13 years, coach of multiple Paralympic medallists from 100 m to marathon. Three-time Paralympian, Athens silver medallist 800 m.

4.2.2 Low Energy Availability: Consequences

LEA can have acute or long-term effects. Even periods of LEA as short as 5 days have been shown to reduce blood glucose and leptin levels, elevate cortisol and increase bone resorption markers in eumenorrheic sedentary women (Loucks et al. 2011; Melin et al. 2015).

If maintained for a longer period, LEA will produce more severe symptoms. LEA has been associated with several alterations, such as (DeSouza et al. 2014; Mountjoy et al. 2018):

- Suppression of resting metabolic rate and hormone production (i.e. thyroid hormones, testosterone and oestrogen)

- Loss of bone mass (increased risk of stress fractures)
- Compromised immunity
- Nutrient inadequacies, reduced muscle protein synthesis, increased production of stress hormones, increased risk of fatigue and therefore of injury
- Reduced responsiveness to training and performance
- Other health and psychological consequences (e.g. eating disorder)

Two important clusters of symptoms that comprise TRIAD and RED-S have also been associated with LEA (Logue et al. 2017; Loucks et al. 2011; Mountjoy et al. 2014). In TRIAD, three interrelated components are present: energy availability, menstrual status and bone health. LEA directly affects menstrual status through hormone suppression, which in turn influences bone health. Athletes' optimal health is indicated by optimal energy availability, eumenorrhoea and optimal bone health. An athlete's condition may move along each component of TRIAD at different rates depending on her diet and exercise behaviours. The most severe presentation of TRIAD is characterised by LEA with or without an eating disorder, functional hypothalamic amenorrhoea and osteoporosis (DeSouza et al. 2014).

Currently, there are scarce data available regarding the prevalence of TRIAD in Para athletes. Blauwet et al. (2017b) evaluated the prevalence of TRIAD in elite Para athletes training to qualify for the 2016 or 2018 Paralympic Games via an online questionnaire. Only 8% (n = 260) of the participants were aware of TRIAD. With no difference in risk factors between leanness and nonleanness sports, or male and female athletes, the authors found that 44% felt pressure to maintain a certain body weight, 3% had previously been diagnosed with an eating disorder, 44% of premenopausal female athletes had less than 10 menstrual cycles in the past 12 months, and 17% had previously experienced a bone stress injury. The interpretation of bone mineral density (BMD) in Para athletes needs to consider the fact that many athletes are at higher risk of low BMD due to their impairment, as outlined in other chapters in this book. As such, it will be difficult to use low BMD as a marker of LEA or TRIAD in many athletes with a physical impairment.

RED-S encompasses TRIAD and other consequences. Long-term LEA is associated with nutrient deficiencies (including anaemia), chronic fatigue and increased risk of infections and illnesses. Physiological and medical complications involve the cardiovascular (due to lipid profile alteration and endothelial dysfunction), gastrointestinal, endocrine, reproductive, skeletal, renal and central nervous systems. Psychological stress and/or depression can result in, or be a result of, LEA and eating disorders. Absent menses may have an emotional impact in creating anxiety (Mountjoy et al. 2014, 2015; Thomas et al. 2016). Hormonal and metabolic abnormalities caused by RED-S and carbohydrate deficiency can result in a reduction in glucose utilisation, mobilisation of fat stores, slowing of metabolic rate and a decreased production of growth hormone (Loucks and Thuma 2003; Mountjoy et al. 2015). Long-term reproductive repercussions of RED-S for women and men are unknown.

4.3 ENERGY AVAILABILITY IN ATHLETES: ASSESSMENT

Due to the important consequences of LEA, an in-depth assessment of EA is desirable, including bone health assessment, haematological evaluation, screening for eating disorders, menstrual history and a more accurate assessment of energy expenditure for both basal metabolic rate and EEE. The subtle symptoms caused by RED-S make its identification a challenge (Mountjoy et al. 2018).

The International Olympic Committee (IOC) developed the Clinical Assessment Tool (RED-S CAT) for both females and males aimed at the screening and management of RED-S, as follows (Mountjoy et al. 2014, 2015):

1. "*High risk – Red light*": athletes should be absent from training for outpatient clinical treatment due to the severity of the clinical condition which may compromise the athlete's health. The main symptoms presented by athletes include eating disorders such as anorexia nervosa, medical conditions (psychological and physiological) related to low energy availability and the adoption of extreme weight loss techniques leading to dehydration-induced hemodynamic instability and other life-threatening conditions.
2. "*Moderate risk – Yellow light*": athletes can train under supervision and clinical treatment. The main symptoms to be monitored include: low body fat percentage, weight loss (more than 5%–10% body mass in 1 month), attenuation of expected growth and development in adolescent athletes, abnormal menstrual cycle (functional hypothalamic amenorrhea for more than 6 months or menarche after the age of 16 years), abnormal hormonal profile in men, reduced BMD (either from last measurement or Z-score <-1), history of one or more stress fractures associated with hormonal/menstrual dysfunction and/or LEA, physical and psychological complications related to LEA or disordered eating, electrocardiogram abnormalities, laboratory abnormalities, prolonged relative energy deficiency, disordered eating behaviour negatively affecting other team members and lack of progress in treatment and/or noncompliance. Evolution should be monitored periodically for the control of the case.
3. "*Low risk – Green light*": athlete can train and compete without any limitations.

The prevalence of RED-S in the Para athlete population has not been described in the literature. However, attention to adequate energy intake should be emphasised (Scaramella et al. 2018).

The Low Energy Availability in Females Questionnaire (LEAF-Q) is a validated tool for evaluating the individual components of TRIAD. With a 78% sensitivity and 90% specificity, it can be used to detect the risk of symptoms associated with LEA and has been proposed for able-bodied female athletes (Melin et al. 2014). A version for male athletes is in development (Mountjoy et al. 2018).

There are a range of studies on EA in athletes, aiming to increase knowledge about the concept and its implications in different sports, a summary of which is presented in Table 4.1.

TABLE 4.1
Summary of Studies on Energy Availability in Different Sports

Authors (Year)	Public	Body Composition	EEE	EI	EA
Hoch et al. (2009)	80 female athletes of varied sports	DXA	PA record converted in MET	3-day food diary	29 athletes presented reduced EA* and 5 athletes presented LEA$^{\alpha}$
Koehler et al. (2013)	352 athletes (167 male athletes and 185 female athletes) of different modalities	BIA	PA record converted in MET	6-day food registry	Median EA values: 28.5 kcal/kgFFM/d for male and 29.4 kcal/kgFFM/d for female athlete
Woodruff and Meloche (2013)	10 female volleyball players	Plethysmography	Accelerometer	7-day food registry	Mean EA: 42.5 kcal/kgFFM/d
Reed et al. (2013)	19 female soccer players	DXA	Heart rate monitor and PA record	3-day diet logs	LEA: 26% preseason, 33% midseason and 12% postseason
Reed et al. (2014)	19 female soccer players	DXA	Heart rate monitor and PA record	3-day diet logs	Preseason: LEA mean value: 19.7 kcal/kgFFM/d and adequate mean EA value: 52.3 kcal/kgFFM/d. Midseason: LEA mean value: 19.5 kcal/kgFFM/d
Coelho et al. (2013)	24 female tennis players	DXA	PA record converted in MET	3-day food record	21 athletes presented reduced EA* and 8 athletes presented LEA$^{\alpha}$

(Continued)

TABLE 4.1 (*Continued*)
Summary of Studies on Energy Availability in Different Sports

Authors (Year)	Public	Body Composition	EEE	EI	EA
Goodwin et al. (2014)	12 female middle runners and 13 female long runners	DXA	Accelerometer	Food weighing	EA mean values of middle runners: 33.2 kcal/kgFFM/d and long runners: 23.2 kcal/kgFFM/d
Łagowska et al. (2014)	31 female athletes (12 rowers, 8 synchronised swimmers, 11 triathletes)	BIA	Heart-rate monitor	7-day food record	Mean EA values 28.3 kcal/kgFFM/d before intervention and 35.8 kcal/kgFFM/d after nutritional intervention
Day et al. (2015)	25 female runners	Skinfolds	Accelerometer	3-day diet recall	EA mean value: 30.8 kcal/kgFFM/d. 23 athletes presented reduced EA and 13 athletes presented LEA
Melin et al. (2015)	40 female athletes of endurance sports	DXA	Heart rate monitor and PA record	7-day food record	15 presented adequate EA (mean value 51.7 kcal/kgFFM/d); 17 presented reduced EA (mean value: 38.5 kcal/kgFFM/d) and 8 presented LEA (mean value 19.1 kcal/kgFFM/d)
Viner et al. (2015)	10 cyclists (6 male and 4 female)	DXA	Heart rate monitor and PA record	3-day dietary records	70% presented LEA preseason, 90% presented LEA during competition and 80% presented LEA off-season.

(*Continued*)

TABLE 4.1 (*Continued*)
Summary of Studies on Energy Availability in Different Sports

Authors (Year)	Public	Body Composition	EEE	EI	EA
Muia et al. (2016)	61 female athletes and 49 female nonathletes	Skinfold	PA diary	5-day weighed dietary record	EA mean values: 36.5 kcal/kgFFM/d for athletes and 39.5 kcal/kgFFM/d for nonathletes
Vescovi and Van Heest (2016)	Case study: 1 triathlete	DXA	Heart rate monitor	5-day diet logs	1st assessment (March): 13.6 kcal/kgFFM/d; 2nd assessment (April): 14.6 kcal/kgFFM/d and 3rd assessment (June): 30.4 kcal/kgFFM/d
Silva and Paiva (2015)	67 female rhythmic gymnasts	BIA	PA record	24-hour food recall	Mean EA values: 32.9 kcal/kgFFM/d for gymnasts 16–18 years old and 29.8 kcal/kgFFM/d for gymnasts 19–26 years old
Stenqvist (2016)	27 cyclists and runners	DXA	Heart rate monitor and activity tracker	3-day weighted food register	18 athletes with EA <40 kcal/kg/FFM/d; 6 had low bone mass density not related to EA status
Heikura et al. (2017)	12 females and 10 male middle- and long-distance runners	DXA	PA record	7-day food record	Mean EA values – female athletes: amenorrheic 32 kcal/kgFFM/d); eumenorrheic: 35 kcal/kgFFM/d. Male athletes with: low testosterone: 31 kcal/kgFFM/d and with normal testosterone: 35 kcal/kgFFM/d

(*Continued*)

TABLE 4.1 (*Continued*)
Summary of Studies on Energy Availability in Different Sports

Authors (Year)	Public	Body Composition	EEE	EI	EA
Schaal et al. (2017)	11 female synchronised swimmers	Skinfold	Heart rate monitor and PA record	4-day food record	Mean baseline EA: 25 kcal/kgFFM/d; 2nd assessment: 22 kcal/kgFFM/d and 3rd assessment: 18 kcal/kgFFM/d
Heikura et al. (2018)	27 female and 21 males middle and long-distance runners	DXA	Training logs	7-day food record	Mean EA values – female: 33 kcal/kgFFM/d and male: 36 kcal/kgFFM/d
Braun et al. (2018)	56 female elite football players	BIA	PA record	7-day food record	Mean EA value: 30 kcal/kgFFM/d

Note: *<45 kcal/kg/FFM/day; $^{\alpha}$<30 kcal/kg/FFM/day
Abbreviations: EEE, exercise energy expenditure; EI, energy intake; EA, energy availability; LEA, low energy availability; DXA, dual-energy x-ray absorptiometry; BIA, bioelectrical impedance analysis; PA, physical activity.

Reed et al. (2013) evaluated the prevalence of LEA in able-bodied USA female collegiate soccer players and demonstrated the importance of following EA throughout the season. In addition to evaluating EA, both Reed et al. (2014) and Braun et al. (2018) examined macronutrient intake and observed low intakes of carbohydrate among athletes with LEA (100% and 31% of the assessed athletes, respectively).

The use of different methodologies makes it difficult to compare results between studies, highlighting the need for tools associated with biochemical parameters (especially leptin, triiodothyronine and cortisol) to identify LEA (Logue et al. 2017; Mountjoy et al. 2018).

Little is known about the physiological effects and prevalence of LEA on the health and performance of male athletes (Mountjoy et al. 2018; Slater et al. 2017). Tenforde et al. (2015) reported that male athletes may present a process analogous to TRIAD, with the following interrelated components: LEA (with or without disordered eating), hypogonadotropic hypogonadism and low bone mineral density. However, Koehler et al. (2016) associated LEA in exercising men with reduced leptin and insulin but not with changes in other metabolic hormones (ghrelin, triiodothyronine, testosterone and IGF-1). These authors suggested a cut-off point of 170 kJ/kgFFM/d (40 kcal/kgFFM/d) as an "adequate" value for identifying LEA in males. LEA may also lead to alterations in testosterone (Mountjoy et al. 2018). Therefore, there is a consensus on the need for further research on LEA in this group (Logue et al. 2017; Mountjoy et al., 2018; Slater et al. 2017).

4.4 ENERGY AVAILABILITY IN PARA ATHLETES

There is little information on EA and its consequences on Para athletes. However, the support team working with these athletes should be aware of the risks and consequences of LEA, as the susceptibility towards LEA is dependent on impairment type and severity (Blauwet et al. 2017a).

In a pioneering study on the evaluation of EA in Para athletes, Joaquim et al. (2018) assessed Paralympic track sprinters (male and female) with vision impairment (VI), cerebral palsy (CP) and limb deficiency (LD, no more than 2.5% of amputation in relation to body mass). Dietary intake was assessed using 24-hour photographic register for 4 consecutive days. Energy expenditure was measured using actigraphy, and FFM was estimated using skinfolds. Using the definition of Loucks et al. (2011), EA was reduced for all athletes [mean intake VI = 150 kJ (36 kcal), LD = 154 kJ (37 kcal) and CP = 158 kJ/kgFFM/day (38 kcal/kgFFM/day)]. Only four athletes showed adequate EA for at least two of the assessed days and none had LEA for more than two days. The authors emphasised that these EA values reflect a specific assessment period in which athletes were not following their usual training and had a greater variety of foods available.

4.4.1 Limitations in Assessing Energy Availability in a Para Population

One of the limitations when studying EA in the Para athlete population is the complexity of determining its components. EA components are influenced by several factors, and the primary concern is about the validity and accuracy of the methods available, as they were not developed for this population.

4.4.1.1 Energy Intake

There are several methods which allow the collection of dietary data, both prospectively and retrospectively. However, they all have limitations which can range from the athletes' memory in reporting their food consumption (e.g. using the 24-hour recall or Food Frequency Questionnaires) to changes in habits while recording their intake (e.g. food diaries) (Mountjoy et al. 2018; Thomas et al. 2016).

In addition to the limitations of the recording tools, many factors influence athletes' food choices and energy intake. A lack of sports nutrition knowledge can result in athletes becoming more vulnerable to inadequate food choices. Athletes may also lack an understanding of true energy requirements. Other aspects such as food allergies/intolerances, economic situation, cooking skills and social context can all impact food choices and are outlined in other chapters in this book.

In the case of athletes with impairments, some additional aspects should be taken into consideration. Athletes with a spinal cord injury (SCI) may be at higher risk of LEA, as they may restrict EI to maintain body mass, which may also lead to nutritional deficiencies such as calcium, magnesium, folate and vitamin D (Blauwet et al. 2017a; Scaramella et al. 2018). Chronic pain, surgical intervention of the gastrointestinal tract at time of injury, internal damage due to accidents or warfare; body posture (some athletes while operating their racing chair will have almost 100% of their body weight resting on their stomach, increasing the feeling of fullness); lower gastric emptying times (i.e. SCI) and feeding difficulties (CP), which includes swallowing, food sensitivities, body posture and selectivity (Chapters 6 and 7; Broad and Juzwiak 2018; Scaramella et al. 2018) can all impact a Para athlete's EI. Athletes with VI may have difficulty in interpreting portion sizes (Juzwiak et al. 2015) and the guide-athletes may play an important role in their food choice as they help them to set up meals (Joaquim et al. 2018). Thus, when assessing energy intake, in addition to methodological limitations, it is necessary to consider general factors that affect food choices, as well as factors related to the specificities of the impairments.

COMMENTARY BOX 4.2

ATHLETE INSIGHT: What are the biggest nutrition challenges you face? In particular, are there any that appear to be different challenges to what your able-bodied counterparts face?

> Living in a boarding school in a country halfway across the world from home (UK), I find it difficult to maintain a balanced diet. Boarders like me end up eating meals prepared by the school which are generally excessively oily and in the wrong portions. Indeed, we have common kitchens in each boarding house for us to cook and prepare our own meals which undoubtedly, would be much healthier. However, due to having only one arm, the time required for food preparation is too long, especially when compared to able-bodied counterparts. In addition with the packed schedule of mine as a student and athlete, I would just rather save the time for resting.

Carmen Lim, Para swimmer (S8)

4.4.1.2 Exercise Energy Expenditure

EEE may be estimated with specific devices; however, these wearable devices have software developed for the able-bodied population. Activity diaries can be converted using values available in kilojoules (kJ) or calories (kcal), or in metabolic units (METs). However, these tables were also established from studies with able-bodied athletes, except for Conger and Bassett (2011), who published values for wheelchair physical activities and Collins et al. (2010), who published values for recreational and daily life activities obtained from telemetry system in adults with spinal cord injury. These tools may be valid in athletes with VI, intellectual impairments and minimal limb deficiency/dysfunction since they are physiologically similar to able-bodied athletes.

Collins et al. (2010) suggest a lower value (2.7 mL/kg/min) as equivalent to 1 MET for nonelite athlete wheelchair users compared to 3.5 mL/kg/min used in healthy adult athletes, which tends to overestimate energy expenditure in athletes most likely due to greater efficiency of movement. Due to sympathetic nervous system impairment, athletes with SCI can have lower VO_{2max}, reduced aerobic capacity and heart rate, and consequently lower EEE compared to able-bodied athletes (Scaramella et al. 2018). Furthermore, the values given by Collins et al. (2010) and Conger and Bassett (2011) may not be relevant for elite athletes whose wheelchairs are much lighter and more aerodynamic. A new generation of multisensor devices, which incorporate algorithms developed using physiological signals and acceleration, estimate the energy expenditure of wheelchair users (Nightingale et al., 2017). This motion sensor provides a reasonable estimate of energy expenditure under laboratory and free-living conditions, yielding results similar to standard conditions (Chowdhury et al., 2017; Zhang et al., 2017).

Athletes with LD, in particular unilateral or bilateral leg amputees, may have a greater energy demand due to gait imbalances (Blauwet et al. 2017a), and the more proximal the amputation, the greater loss of tissue, and higher EEE during movement (Chapter 8). CP athletes may have a higher or lower EEE depending on the degree of neurological damage; functional movement capability and the presence of athetosis, spasticity or ataxia (Chapter 7). As such, wearable devices may not be valid for this population because they have internal programming software that is based on an able-bodied population, whose validity is uncertain in many Para athlete populations (e.g. dwarfs, unilateral CP, other neurological disorders). Tsang et al. (2016), in a systematic review on the validity of activity monitors in wheelchair users, suggested that these devices can lead to overestimating energy expenditure of movement. Furthermore, the physiological profiles of many Para-sports have not been described in the literature (e.g. goalball, sit volleyball) and there is no "equivalent" able-bodied sport with which to compare (Broad and Juzwiak 2018).

4.4.1.3 Body Composition Assessment

Anthropometric assessment is a major challenge, both regarding taking the measurements (even the most basic measures such as body mass and height can be challenging) and in the estimation of body composition, as predictive indexes and equations available are not validated for the full variety of impairment types.

There are numerous methods for assessing the body composition of athletes, and a full description of these methods and their limitations is outlined in Chapter 13.

For Para athletes, one must take into account their individual characteristics and the specificities of the impairment, which may have implications in the use of the available method and the interpretation of the data, as they may violate the underlying assumptions of the method (Blauwet et al. 2017a).

Briefly, dual-energy x-ray absorptiometry (DXA) has been considered an accurate method to assess bone mineral content and density, as well as fat mass (FM) and FFM. However, the correct positioning of the athlete when contractures are present may be a challenge, and DXA is not indicated for individuals with spasms (e.g. some SCI, multiple sclerosis and CP) and metal fixtures (e.g. surgical pins and rods), which may alter scan accuracy. Bioelectrical impedance analysis (BIA) is not indicated in the presence of oedema (e.g. SCI due to change in total body water content and intra- and extracellular water ratios) or amputations (missing unilateral or lower limbs will impact whole body resistance measurement), and may underestimate FFM in SCI athletes relative to DXA (Broad and Juzwiak 2018). Air displacement plethysmography (ADP) requires athletes to sit upright on their own (which is not possible in higher-level SCI) and assumes constant density of body tissues, which may not be valid where muscle atrophy is present (Chapter 13).

The sum of skinfolds for the longitudinal monitoring of body composition of athletes with impairments, avoiding the use of nonspecific predictive equations for this population, has been suggested as a useful mechanism to track body composition changes over time (Chapter 13); however, FFM estimation is fundamental for the determination of EA. The use of predictive equations to convert skinfolds to percent body fat, even though nonspecific for this population, has been used in some studies (Gomes et al. 2006; Joaquim et al. 2018; Juzwiak et al. 2016). However, Juzwiak et al. (2016) and Joaquim et al. (2018) assessed athletes who are physiologically similar to able-bodied athletes, such as VI, athletes with LD representing less than 2.5% of body mass and athletes with minimal impact CP. Regression equations to estimate FFM for wheelchair games players were proposed by Goosey-Tolfrey et al. (2016); however, these equations used skinfold sites in areas with muscle atrophy, the validity of which is undetermined; involved a wide range of impairments; and used DXA as the "gold standard" tool, which has not yet been validated for body composition in individuals with substantial muscle atrophy (Broad and Juzwiak 2018).

Studies validating DXA, BIA, ADP and specific equations to determine FFM in athletes with a range of impairments are necessary.

4.5 CONCLUSION

Athletes should be encouraged to consume adequate amounts of energy to meet their physiological demands and EEE, guaranteeing adequate energy availability and avoiding health and performance impairment.

EA assessment in the Para athlete poses a challenge that requires careful evaluation of athletes' characteristics in order to select the best evaluation method. Little is known about the prevalence and consequences of LEA in Para athletes. Future research is critical to understand how LEA affects athletes with an impairment and the different functional classifications. Furthermore, professionals who work directly with athletes should be aware of the consequences of LEA.

REFERENCES

Blauwet, C.A., Brook, E.M., Tenforde, A.S. et al. 2017a. Low energy availability, menstrual dysfunction, and low bone mineral density in individuals with a disability: Implications for the Para athlete population. *Sports Medicine* 47:1697–1708.

Blauwet, C.A., Brook, E.M., Tenforde, A.S., Broad, E.M. and Matzkin, E.G. 2017b. An analysis of female athlete triad components in elite Para-athletes. *Medicine and Science in Sports and Exercise* 49(5S):667.

Braun, H., Werburg, J.A., Schänzer, W. and Thevis, M. 2018. Nutrition status of young elite female German football players. *Pediatric Exercise Science* 30:157–167.

Broad, E. and Juzwiak, C. 2018. Sports nutrition in Para athletes – determining energy requirements. *Aspetar Sports Medicine Journal* 7:170–175.

Burke, L.M., Loucks, A.B. and Broad, N. 2006. Energy and carbohydrate for training and recovery. *Journal of Sports Sciences* 24:675–685.

Chowdhury, E.A., Western, M.J., Nightingale, T.E., Peacock, O.J. and Thompson, D. 2017. Assessment of laboratory and daily energy expenditure estimates from consumer multi-sensor physical activity monitors. *PLOS ONE* 12:e0171720.

Coelho, G.M.O., Farias, M.L.F., Mendonça, L.M.C. et al. 2013. The prevalence of disordered eating and possible health consequences in adolescent female tennis players from Rio de Janeiro, Brazil. *Appetite* 64:39–47.

Collins, E.G., Gater, D., Kiratli, J., Butler, J., Hanson, K. and Langbein, W.E. 2010. Energy cost of physical activities in persons with spinal cord injury. *Medicine and Science in Sports and Exercise* 42:691–700.

Conger, S.A. and Bassett, D.R. 2011. A compendium of energy costs of physical activities for individuals who use manual wheelchairs. *Adapted Physical Activity Quarterly* 28:310–325.

Day, J., Wengreen, H., Heath, E. and Brown, K. 2015. Prevalence of low energy availability in collegiate female runners and implementation of nutrition education intervention. *Sports Nutrition and Therapy* 1:1–7.

DeSouza, M.J., Nattiv, A., Joy, E. et al. 2014. 2014 Female Athlete Triad Coalition Consensus Statement on treatment and return to play of the female athlete triad. *British Journal of Sports Medicine* 48:1–20.

Gomes, A.I.S., Ribeiro, B.G. and Soares, E.A. 2006. Nutritional characterization of elite amputee soccer players. *Revista Brasileira de Medicina do Esporte* 11:17–21.

Goodwin, Y., Monyeki, M.A., de Ridder, J.H. et al. 2014. Association between energy availability and menstrual function in elite Kenyan runners. *African Journal for Physical, Health Education, Recreation and Dance* 20:291–307.

Goosey-Tolfrey, V., Keil, M., Brooke-Wavell, K. and Groot, S.A. 2016. Comparison of methods for the estimation of body composition in highly trained wheelchair games players. *International Journal of Sports Medicine* 37:799–806.

Heikura, I.A., Burke, L.M., Bergland, D., Uusitalo, A.L.T., Mero, A.A. and Stellingwerff, T. 2018. Impact of energy availability, health and sex on hemoglobin mass responses following live-high-train-high altitude training in elite female and male distance athletes. *International Journal of Sports Physiology and Performance* 12:1–26.

Heikura, I.A., Uusitalo, A.L.T., Stellingwerff, T., Bergland, D., Mero, A.A. and Burke, L.M. 2017. Low energy availability is difficult to assess but outcomes have large impact on bone injury rates in elite distance athletes. *International Journal of Sport Nutrition and Exercise Metabolism* 18:1–30.

Hoch, A.Z., Pajewski, N.M., Moraski, L. et al. 2009. Prevalence of the female athlete triad in high school athletes and sedentary students. *Clinical Journal of Sport Medicine* 19:421–428.

Ihle, R. and Loucks, A.B. 2004. Dose–response relationships between energy availability and bone turnover in young exercising women. *Journal of Bone and Mineral Research* 19:1231–1240.

Joaquim, D.P., Juzwiak, C.R. and Winckler, C. 2018. Do Paralympic track and field athletes have low energy availability? *Brazilian Journal of Kinanthropometry and Human Performance* 20:71–81.

Juzwiak, C.R., Frutuoso, M.F.P., Lourenço, L.A. et al. 2015. Percepciones sobre el comer de atletas deficientes visuales de alto rendimiento. In *IV Congreso Internacional del Observari d'Alimentació y Fundació Alicia – Otras Maneras de Comer: Elecciones, Convicciones y Restricciones*, 1400–1417. Barcelona: Spain.

Juzwiak, C.R., Winckler, C., Joaquim, D.P., Silva, A. and de Mello, M.T. 2016. Comparison of measured and predictive values of basal metabolic rate in Brazilian Paralympic track and field athletes. *International Journal of Sport Nutrition and Exercise Metabolism* 26:330–337.

Koehler, K., Achtzehn, S., Braun, H., Mester, J. and Schaenzer, W. 2013. Comparison of self-reported energy availability and metabolic hormones to assess adequacy of dietary energy intake in young elite athletes. *Applied Physiology, Nutrition, and Metabolism* 38:725–733.

Koehler, K., Hoerner, N.R., Gibbs, J.C. et al. 2016. Low energy availability in exercising men is associated with reduced leptin and insulin but not with changes in other metabolic hormones. *Journal of Sports Sciences* 34:1921–1929.

Łagowska, K., Kapczuk, K., Friebe, Z. and Bajerska, J. 2014. Effects of dietary intervention in young female athletes with menstrual disorders. *Journal of the International Society of Sports Nutrition* 11:21.

Logue, D., Madigan, S.M., Delahunt, E., Heinen, M., McDonnell, S.J. and Corish, C.A. 2017. Low energy availability in athletes: A review of prevalence, dietary patterns, physiological health, and sports performance. *Sports Medicine* 48:73–96.

Loucks, A.B., Kiens, B. and Wright, H.H. 2011. Energy availability in athletes. *Journal of Sports Sciences* 29(Suppl. 1):S7–S15.

Loucks, A.B. and J.R. Thuma. 2003. Luteinizing hormone pulsatility is disrupted at a threshold of energy availability in regularly menstruating women. *The Journal of Clinical Endocrinology & Metabolism* 88:297–311.

Loucks, A.B., Verdun, M. and Heath, E.M. 1998. Low energy availability, not stress of exercise, alters LH pulsatility in exercising women. *Journal of Applied Physiology* 84:37–46.

Manore, M., Brown, K., Houtkooper, L. et al. 2014. Energy balance at a crossroads: Translating the science into action. *Medicine and Science in Sports and Exercise* 46:1466–1473.

Matzkin, E., Curry, E.J. and Whitlock, K. 2015. Female athlete triad: Past, present, and future. *Journal of the American Academy of Orthopaedic Surgeons* 23:424–432.

Melin, A., Tornberg, A.B., Skouby, S. et al. 2014. The LEAF questionnaire: A screening tool for the identification of female athletes at risk for the female athlete triad. *British Journal of Sports Medicine* 48:540–545.

Melin, A., Tornberg, A.B., Skouby, S. et al. 2015. Energy availability and the female athlete triad in elite endurance athletes. *Scandinavian Journal of Medicine and Science in Sports* 25:610–622.

Moreiras, G.V., Ávila, J.M. and Ruiz, E. 2015. Energy balance, a new paradigm and methodological issues: the ANIBES study in Spain. *Nutrición Hospitalaria* 31(Suppl. 3):101–112.

Mountjoy, M., Sundgot-Borgen, J., Burke, L. et al. 2014. The IOC consensus statement: beyond the female athlete triad - Relative energy deficiency in sport (RED-S). *British Journal of Sports Medicine* 48:491–497.

Mountjoy, M., Sundgot-Borgen, J., Burke, L. et al. 2015. Authors' 2015 additions to the IOC consensus statement: Relative energy deficiency in sport (RED-S). *British Journal of Sports Medicine* 49:417–420.

Mountjoy, M, Sundgot-Borgen, J., Burke, L. et al. 2018. International Olympic Committee (IOC) Consensus Statement on relative energy deficiency in sport (RED-S): 2018 update. *International Journal of Sport Nutrition and Exercise Metabolism* 28:1–19.

Muia, E.N., Wright, H.H., Onywera, V.O. and Kuria, E.N. 2016. Adolescent elite Kenyan runners are at risk for energy deficiency, menstrual dysfunction and disordered eating. *Journal of Sports Sciences* 37:598–606.

Nightingale, T.E., Rouse, P.C., Thompson, D. and Bilzon, J.L.J. 2017. Measurement of physical activity and energy expenditure in wheelchair users: methods, considerations and future directions. *Sports Medicine - Open* 3:10.

Reed, J., Souza, M.J. and Williams, N. 2013. Changes in energy availability across the season in Division I female soccer players. *Journal of Sports Sciences* 31:314–324.

Reed, J.L., Souza, M.J., Kindler, J.M. and Williams, N. 2014. Nutritional practices associated with low energy availability in Division I female soccer players. *Journal of Sports Sciences* 32:499–509.

Scaramella, J., Kirihennedige, N. and Broad, E. 2018. Key nutritional strategies to optimize performance in Para athletes. *Physical Medicine and Rehabilitation Clinics of North America* 29:283–298.

Schaal, K., Tiollier, E., LeMeur, Y., Casazza, G. and Hausswirth, C. 2017. Elite synchronized swimmers display decreased energy availability during intensified training. *Scandinavian Journal of Medicine and Science in Sports* 27:925–934.

Silva, M.R.G. and Paiva, T. 2015. Low energy availability and low body fat of female gymnasts before an international competition. *European Journal of Sport Science* 15:591–599.

Slater, J., Brown, R., McLay-Cooke, R. and Black, K. 2017. Low energy availability in exercising women: Historical perspectives and future directions. *Sports Medicine* 47:207–220.

Stenqvist, T.B. 2016. Prevalence of relative energy deficiency in sport among well-trained male Norwegian cyclists and long-distance runners. [*Master thesis*]. University of Agder, Norway.

Stubbs, R.J., Johnstone, A.M., Whybrow, S. et al. 2004. Rate and extent of compensatory changes in energy intake and expenditure in response to altered exercise and diet composition in humans and expenditure in response to altered exercise and diet composition in humans. *American Journal of Physiology. Regulatory, Integrative and Comparative Physiology* 286:350–358.

Tenforde, A.S., Barrack, M.T., Nattiv, A. and Fredericson, M. 2015. Parallels with the female athlete triad in male athletes. *Sports Medicine* 46:171–182.

Thomas, D.T., Erdman, K.A. and Burke, L.M. 2016. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and athletic performance. *Journal of the Academy of Nutrition and Dietetics* 116:501–528.

Tsang, K., Hiremath, S.V., Crytzer, T.M., Dicianno, B.E. and Ding, D. 2016. Validity of activity monitors in wheelchair users: A systematic review. *Journal of Rehabilitation Research and Development* 53:641–658.

Vescovi, J.D. and Van Heest, J.L. 2016. Case study: Impact of inter- and intra-day energy parameters on bone health, menstrual function, and hormones in an elite junior female triathlete. *International Journal of Sport Nutrition and Exercise Metabolism* 26:363–369.

Viner, R.T., Harris, M., Berning, J.R. and Meyer, N.L. 2015. Energy availability and dietary patterns of adult male and female competitive cyclists with lower than expected bone mineral density. *International Journal of Sport Nutrition and Exercise Metabolism* 25:594–602.

Woodruff, S.J. and Meloche, R.D. 2013. Energy availability of female varsity volleyball players. *International Journal of Sport Nutrition and Exercise Metabolism* 23:24–30.

Zhang, P., Witmer, C., Godin, S. et al. 2017. Validating iWatch in measuring energy expenditure during different levels of physical activity. *Medicine and Science in Sports and Exercise* 49(Suppl. 5):364–365.

5 Cooling and Hydration for the Para Athlete

Kelly Pritchett, Robert Pritchett and Elizabeth Broad

CONTENTS

5.1 INTRODUCTION

Body core temperature (T_{core}) regulation is important because cellular and metabolic functions are affected by modest deviations from the human normal of ~37°C. In an extreme case where T_{core} reaches temperatures above 41°C, enzyme structure starts to be altered, causing an inability to produce cellular energy (ATP) and eventually death. A reduction below 34°C can cause a decrease in metabolism and possible abnormal cardiac function (Periard et al. 2015). Since there are such large metabolic and environmental temperature impacts and extreme consequences in humans with relatively small variations in core temperature, it is vital that T_{core} be efficiently regulated. Core temperature rises when net heat gain exceeds heat loss, which is especially common during the combination of vigorous exercise (internal heat generation) in a hot, humid environment (external heat). The opposite is true in the cold, where heat loss can exceed heat gain. During vigorous activity, metabolic responses increase 20–25 times above rest, which could amount to an increase of 1°C every 5–7 minutes if it were not for some means to dissipate this heat. Fortunately, heat leaves the body via a number of mechanisms such as radiation, conduction and convection, with the latter being by far the most efficient of these, particularly when there is effective evaporation of fluid from the skin surface to the atmosphere. The drive to maintain a thermal balance is optimised by a sweat rate of up to 2 L/h in able-bodied individuals, allowing for large heat losses, especially in a low-humidity environment.

The Para athlete, however, faces many unique challenges related to thermoregulation and hydration. Athletes with spinal cord injuries (SCIs) have an impaired ability to thermoregulate because of the reduced sudomotor and autonomic response below the level of their lesion, thus making vigorous activity in the heat a challenge from a thermal balance perspective (Griggs et al. 2015b; Pritchett et al. 2015). While individuals with a SCI generally have a loss of motor function, which will likely reduce the heat production side, a lack of voluntary bowel and bladder control, and often inconvenient bathroom access, may lead to an intentional reduction in fluid intake, which increases their chances of dehydration. This results in fatigue, reduced performance and sweating (heat loss), plus an increased risk of urinary tract infections, spasms, heat exhaustion and heat stroke, cramping and injury (Scaramella et al. 2018). Clear strategies for meeting fluid requirements and cooling needs should be individualised to the athlete as a high priority.

This chapter discusses thermoregulatory and hydration challenges for athletes with an impairment. Strategies for cooling, plus assessment and implementation of appropriate hydration methods, are important for all Para athletes but crucial for athletes who are performing at high levels at events like the summer Paralympic games, which are typically hosted in locations with challenging environmental conditions.

5.2 ABNORMAL SWEAT RATES AND POOR THERMOREGULATION IN THE PARA ATHLETE

Complete or partial loss of neural function below the level of spinal cord injury creates a unique set of challenges for athletes with a SCI. The reduced afferent information to the thermoregulatory centre results in the individual being unable to initiate normal thermal regulatory mechanisms such as sweating and peripheral blood redistribution. The result is greater increases in T_{core} at a given exercise and/or heat load compared to able-bodied persons (Griggs et al. 2015b). Additionally, athletes with SCI have weakened autonomic nervous system control, which results in a reduced sweat response below the level of their spinal cord injury (Pritchett et al. 2015). As blood-flow redistribution and sweating are two major thermoregulatory mechanisms to mitigate a change in body temperature, athletes with a SCI exhibit an impaired ability to thermoregulate because of a mismatch between heat production or gain and dissipation (Forsyth et al. 2016; Griggs et al. 2015b; Price 2006). Athletes with a higher level and/or completeness of the spinal lesion may experience greater difficulty dissipating heat and maintaining T_{core} since there is a larger proportion of their body that does not contribute to heat loss. In other words, individuals with high-level lesions (quadriplegia) are at a greater risk of heat illness than individuals with lower-level lesions (paraplegia) at a given exercise intensity, even in thermoneutral conditions (Griggs et al. 2015a). Consequently, they may experience premature onset of fatigue and performance decrements (Forsyth et al. 2016).

Athletes with multiple sclerosis may also experience impairments to the thermoregulatory capacity due to altered neurological responses and reduced sweating responses (Davis et al. 2010). This commonly results in increased fatigue and symptomology specific to the sites of multiple sclerosis damage. This may also be a concern in athletes with acquired brain injuries and cerebral palsy, although there is nothing documented in the research literature. Amputees may also be at higher risk of heat-related issues than able-bodied athletes due to small skin surface area to dissipate heat. The influence of other impairment types on thermoregulatory capacity remains unexplored; therefore, individual assessments of heat tolerance and parameters enabling effective heat loss are important.

EXPERT COMMENTARY BOX 5.1

SPECIAL COMMENTARY: Heat stress during a Paratriathlon

For 2 consecutive years, Ben Stephenson collected core temperature and thermal strain data on Paratriathletes at a race in Italy where conditions were hot but not humid. The participants covered all classes of Paratriathlon (physical and vision impairments). A total of 28 athletes participated in the study. Some of the key outcomes were:

- For those who chose to wear wetsuits during the swim leg (750 m), core temperatures were rising even before they started the swim.
- Core temperature rose by an average of 0.7°C over the course of the swim (official water temperature was 25–27°C), with greater rises in those wearing wetsuits and minimal differences between impairment types.
- During the bike (20 km), core temperatures plateaued in two-wheel cyclists but continued to rise in the hand cyclists. The difference is likely due to a number of reasons, including reduced surface area for convective heat loss and a greater surface area exposed to radiant heat off the road surface in hand cyclists.
- During the run (5 km), the opposite occurred – ambulant runners increased core temperature an average of 1.0°C, whereas the wheelchair athletes tended to plateau.
- Core temperatures at the end of the race were generally quite high. Twenty-two athletes were over 39.5°C, of which eight were over 40°C. There was a higher proportion of heat stress symptoms in those who'd worn a wetsuit during the swim.

Ben Stephenson, PhD candidate, Loughborough University

5.3 COOLING STRATEGIES FOR THE PARA ATHLETE

Methods such as ice vest cooling, ice slurry ingestion, ice packs, cold-water immersion or a combination of these can reduce T_{core} prior to the start of exercise, thereby delaying the time to reach critically high levels during exercise and improving exercise performance in the heat (Bongers et al. 2015; Ross et al. 2013). Cooling athletes during the course of exercise, such as the continued use of ice vests, ice packs and ingestion of cool fluids, has also been shown to improve performance in the heat (Bongers et al. 2015). While some of these cooling techniques are limited in their use due to logistical issues (such as whole-body cold-water immersion for athletes with SCI), financial outlay and portability, Para athletes in certain sports use cooling strategies which are economical and portable, such as control of gym temperatures for indoor sports (e.g., wheelchair rugby), the use of artificial sweat (water applied via a spray bottle) and orbital fans to great effect.

5.3.1 Cooling Garments

Able-bodied athletic populations have for over two decades used various cooling garments ranging from very bulky types that pump cold water through fine tubes built into the garment to those that have pockets for ice packs. If designed correctly, the garment can be used during exercise; however, there is generally a trade-off between cooling capacity, a design that doesn't hinder movement and weight. In an able-bodied population, ice vests have proven effective in improving performance when used before exercise by around 3.4% and up to 21.5% when used during exercise (Bongers et al. 2015). Two investigations have examined the effects of a cooling vest on physiological outcomes in athletes with a SCI. Webborn and colleagues (2005) performed a repeated exercise bout protocol in eight quadriplegics mimicking the intermittent nature of wheelchair tennis and rugby. Athletes were asked to wear an ice vest either 20 minutes before exercise only or during warm-up plus exercise and were compared to a control condition with no cooling measures at 32°C, 50% relative humidity (Webborn et al. 2005, 2010). Following the completion of fourteen 2-minute bouts of intermittent sprint arm crank ergometer work, it was found that precooling with an ice vest helped to delay an increase in T_{core} until later in the exercise session and resulted in a significantly lower T_{core} at each time point when compared to the control conditions (Webborn et al. 2005). While there was no difference in work done over the 28 minutes of exercise, a more extended exercise protocol of up to 30 sprints showed benefits of both pre- and during-exercise cooling on total number of sprints achieved and a preservation of peak power output in the during-exercise cooling (Webborn et al. 2010). Using the ice vest during the exercise significantly tempered the rise in T_{core} and both pre- and during-exercise cooling reduced the rating of thermal stress. Conversely, Trbovich et al. (2014) examined the effect of a cooling vest (15°C) on core temperature in 17 athletes with SCI versus able-bodied athletes during a 60-minute wheelchair basketball or rugby session in a thermoneutral environment (21.1°C). The vest was not fully effective at attenuating an increase in T_{core}, as hyperthermia (defined as T_{core} max > 37.8°C) was seen in all SCI athletes and 16 of the 19 able-bodied athletes, with the quadriplegic athletes demonstrating the greatest increases in T_{core} when compared to paraplegic and able-bodied athletes (Trbovich et al. 2014). Athletes reported the vests felt heavy and bulky, which may negatively impact performance, although on average the athletes reported that they did feel cooler. Since the ice packs were not changed in the 60 minutes of exercise, it is very possible that the vest created a warm microclimate at the interface between the skin and vest which meant the cooling effect over time was no different to that of the ambient conditions and at worst acted as an insulator.

External cooling of the head and neck has been undertaken because of their uniquely high concentration of thermal receptors; however, the extent to which the change in brain temperature affects exercise performance is not well understood. In a study of six Paralympic shooters, rifle shooters wore a neck and head garment, and pistol shooters wore head and neck garments plus an ice vest on their torso. The garments were renewed regularly throughout the 90-minute trial at the environmental conditions of 32°C and 50%–60% relative humidity. All athletes were exposed to a competition-like setting with and without the cooling garments and comparisons were made to a thermoneutral control condition. While no change in shooting performance was found in the 90-minute trial, the cooling garments improved thermal comfort and suppressed the elevation in tympanic temperature (Broad 1998). Goosey-Tolfrey et al. (2008a) used cooling head and neck garments (replaced every 10 minutes) over a 60-minute tennis simulation at 30.4°C and 54% humidity in eight wheelchair tennis players. The cooling garments resulted in slightly lower ratings of thermal sensation and perceived exertion plus a reduced fluid intake during exercise. While lower fluid intakes may be concerning, their results showed that fluid intakes better matched sweat rates than during the control trial, resulting in no change in body weight across the exercise period (in other words, the cooling garments prevented overdrinking in the hot conditions).

In summary, the use of an ice vest shows promise for both pre- and during-exercise cooling in hot conditions, especially with higher-level SCI. However, the vest or ice packs should be renewed frequently to sustain the temperature differential and should be trialled in advance to determine the best use for each individual. Furthermore, athletes and coaches need to take into consideration the cost-benefit ratio of the intended cooling garment and be aware of how using cooling garments may alter how well the athlete matches fluid intake to sweat loss. Reinforcing appropriate hydration strategies in the heat is an important adjunct to using cooling garments.

5.3.2 Water Immersion

Cold-water immersion is considered by some the gold standard for effective heat dissipation and as such has been used to mitigate heat accumulation in individuals with exertional heat gain. Pre-event whole-body cold-water immersion has been demonstrated to improve performance in the heat in able-bodied athletes by reducing the maximum T_{core} achieved during exercise by an average of 0.2°C (Bongers et al. 2015). Forsyth et al. (2016) assessed 10-minute whole-body cold-water (15.8°C) immersion in 16 wheelchair basketball players with a SCI and found a significant 1.58°C reduction in T_{core} 40 min postcooling (seated in a thermoneutral environment). No exercise was undertaken in this study; hence, the performance effects are unknown, but the authors proposed that this strategy may assist in tolerating exercise in warm conditions.

In SCI athletes, 10 minutes of cold-water hand immersion (both hands immersed up to the wrist in 10°C water) after a 60-minute intermittent exercise protocol at 30.8°C and 60% humidity has been shown to be effective in improving subsequent 1-km time trial performance by 20.5 seconds (Goosey-Tolfrey et al. 2008b). While the performance difference was statistically insignificant between hand-cooling and no cooling due to high variability in performance between athletes, a 20.5-second improvement over 1 km has real implications for elite athletes (Goosey-Tolfrey et al. 2008b). However, it is important to note that athletes did not enjoy hand cooling, with complaints of numbness, lack of grip and blistering (Goosey-Tolfrey et al. 2008b). This suggests that hand cooling by way of immersion may not be practical for sports in which hand dexterity is crucial to both game play and day-to-day mobilisation.

5.3.3 Artificial Sweat

Amongst the able-bodied population, sweat evaporation plays an important role in releasing heat from the body during exercise, mitigating the rise in core temperature and preventing consequent performance impairments. Athletes with a SCI who play court sports tend to use water sprays in front of a fan during rest periods to mimic the sweat response that able-bodied athletes would experience. This is an easy, cheap and accessible means of heat dissipation for athletes. Only one study to date has investigated the effectiveness of artificial sweat in individuals with a SCI. Pritchett et al. (2010) employed a ramped arm crank protocol amongst a group of athletes with paraplegia recruited from a university basketball team. Athletes sprayed themselves over the face, chest and arms ad libitum during a 1-min break between 7-min work stages at 21°C and 55% humidity without a fan. The authors found no statistical difference in physiological, perceptual measures or work performance. The lack of positive results could be due to the conservative change in core temperature (0.5°C) by the end of the work bout, likely related to the moderate ambient temperatures used in the trial. There is evidence, however, that spraying the face with water has a favourable change in thermal comfort ratings (Cotter and Taylor 2005), but this information should be used with caution as a change in comfort that doesn't match a drop in core temperature could potentially override signs of heat strain. More research and practical monitoring are clearly needed for external and artificial sweat regimes.

5.3.4 Ice Slurry Ingestion

Pre-exercise ice slurry ingestion has been shown to improve performance by 6.3% in able-bodied athletes (Bongers et al. 2015), but limited work has been completed on the efficacy of pre-exercise ice slurry ingestion in Para athletes. Forsyth et al. (2016) compared the effects of: (1) cold water immersion, (2) ice slurry ingestion (6.8 g/kg) and (3) combination of ice slurry (6.8 g/kg) with the topical application of iced towels to a normal room-temperature beverage among wheelchair basketball athletes with a SCI. Following 20-minute precooling, athletes rested for 60 minutes in a thermoneutral environment while skin and core temperatures were measured. Cold-water immersion elicited the greatest reduction in both core and skin temperature over the rest period, while ice slurry ingestion produced limited physiological impact

(Forsyth et al. 2016). However, when ice slurry was combined with the application of iced towels to the legs, torso and back/arms, T_{core} was reduced at 20 and 30 minutes postcooling compared to the control condition (Forsyth et al. 2016). Notably, subjects in all precooling groups reported feeling cooler, on a scale of thermal comfort, compared to the control (Forsyth et al. 2016). A recent study using the same volume of ice slurry for 20 minutes leading into a 60-minute wheelchair rugby practise session demonstrated a delay in T_{core} rise up to the midpoint of the session, indicating that ice slurry ingestion does have a practical and effective impact (Moore 2018). Furthermore, the capacity for work performed late in the practise was increased, although the athletes did find the volume of ice slurry difficult to ingest. Therefore, ice slurry is an easy and cost-effective means of reducing core temperature before and during the initial phase of exercise in athletes with SCI and may improve work capacity. However, care must be taken to monitor thermal stress in these athletes to ensure safety, and further work is required to determine the ideal volume and combination of cooling strategies.

5.3.5 Pre- and During-Exercise Cooling Combination

Only one study has considered the combined effect of pre- and during-exercise cooling strategies (Griggs et al. 2017). They had seven quadriplegic athletes undertake a 60-minute intermittent sprint protocol (wheelchair rugby simulation) using a wheelchair ergometer in thermoneutral conditions of 20°C and 33% humidity. The athletes undertook three conditions: (1) not cooled; (2) precooled with an ice vest for 15 minutes of rest, then the 20 minute warm-up; and (3) precooled together with a water spray on the arms, face and torso at the end of each quarter of the intermittent sprint protocol. There was no significant change in T_{core} at the end of the precooling period; however, both cooling strategies dampened the rise in T_{core} over the duration of the exercise bout. There was no effect on performance or perceptual responses; however, the reduction in thermal strain is likely to carry benefits in higher ambient temperatures (Griggs et al. 2017).

5.3.6 Subjective Ratings of Coolness

Research is limited as to performance benefits of precooling in athletes with SCI. Due to the highly variable nature of the population, it is difficult to ensure a high level of ecological validity. While a number of studies note little to no effect on T_{core} following cooling, subjective ratings of coolness must also be considered (Pritchett et al. 2010; Trbovich et al. 2014). Goosey-Tolfrey and colleagues (2008b) concluded that external cooling usually lowers skin temperature, thermal sensation and in turn a decrease in psychological stress. This could be favourable from a work intensity perspective provided athletes are monitored for signs of heat stress.

5.3.7 Duration and Timing of Cooling

Both internal and external precooling techniques require at least 15–60 minutes of exposure to elicit any significant reduction in T_{core} and ideally should be conducted close to the start of exercise and during the warm-up period (Griggs et al. 2015b). While game play schedules can make this challenging, a combination of these precooling methods can reduce the time it takes to lower core temperature to appropriate levels; however, if not monitored well, it could also impair performance in short-duration high-intensity events or when cooling is used between exercise bouts (Ross et al. 2013).

In summary, practical strategies for Para athletes in the field could include the combination of cold-water immersion (where practical), cooling vests, ice towels and ice slurry ingestion pre-exercise; or water dumps (e.g., hand cycling), water sprays in front of fans (court sports), neck coolers (shooting, archery) or ice packed in a stocking nestled between clothes and skin (cycling, triathlon, marathon racing). All strategies should be trialled in advance, and likely in combination, to ensure each athlete can decide on what is best for their individual needs. These should not only be considered in the heat, but also in thermoneutral conditions for athletes with quadriplegia or more severe thermoregulatory impairments.

5.4 HEAT ACCLIMATION

It has been recognised for a long time that humans can gradually adjust to hot climates. With deliberate heat acclimation, decreases are found in heart rate and skin and core temperature over a period of 24 days, with the major adjustment within the first 4–7 days (Periard et al. 2015). Other adaptive responses include an increase in sweat rate and onset of sweating at a lower body temperature, improved heat tolerance and metabolism. Furthermore, upon full acclimation, there is an increase in plasma volume due to an increased perfusion in the cutaneous interstitial space (Periard et al. 2015), resulting in an improved ability to dissipate heat. While daily heat exposure for 10–14 days is believed to stimulate the most complete acclimation (Racinais et al. 2015), heat exposure every 2–3 days over a longer period may also achieve the same outcome and may help prevent excessive fatigue and dehydration in elite athletes (Periard et al. 2015). Acclimation is best achieved by exercising in the heat for at least 60 minutes at a controlled intensity; however, passive exposure does result in some adaptation. These acclimation sessions must be considered an additional stress to the normal training load and it is also important to use both exercise and environmental conditions close to those that will be experienced in competition in order to improve the specificity of the adaptations (Periard et al. 2015; Racinais et al. 2015). Heat acclimation can be retained for about 3 weeks without additional exposure.

Cooling interventions to offset thermoregulatory challenges are relatively acute; therefore, it stands to reason that heat acclimation could be of major benefit to Para athletes either with or without thermoregulatory impairments. Castle et al. (2013) undertook a heat acclimation trial in five Paralympic shooters with a SCI. Athletes completed a 60-min heat acclimation protocol (20 min of arm crank and 40 min of target shooting) for 7 consecutive days at 33.4°C and 64.8% humidity. Investigators originally hypothesised that there wouldn't be an adaptive response to heat acclimation; however, athletes demonstrated a drop in body temperature plus perceptual ratings of exertion and thermal sensation during exercise over the 7 days. Furthermore, there was an increase in plasma volume of 1.5% from day 1 to day 7, indicating that even a relatively small stimulus can induce heat acclimation (Castle et al. 2013). In contrast, over 7 days of exposure, a group of five individuals with quadriplegia and five athletes with paraplegia working for 30 minutes/day at 50% of their VO_{2peak} in a hot (35°C) environment experienced no change in perceptual and physiological measures. Body temperature was similar between day 1 and day 7 for both groups of athletes, with the quadriplegic group experiencing a greater aural temperature than the paraplegic group (Trbovich et al. 2016). The difference in thermal responses between the two groups is consistent with Griggs et al. (2015a), who demonstrated a greater thermal strain for quadriplegic athletes when compared to paraplegic athletes when matched for external workloads. Possibly the lack of acclimation was related to a combination of insufficient duration and intensity of exercise or inconsistency of responses with small subject numbers failing to show statistical significance. Further research is required to determine the potential for heat acclimation to assist Para athletes when exercising in the heat.

EXPERT COMMENTARY BOX 5.2

EXPERT COMMENTARY: Do you believe it is worthwhile having Para athletes undertake heat acclimation work ahead of competing in a hot climate?

> Yes, there is a potential performance advantage in undertaking heat acclimation prior to competing in a hot environment which applies to all Para athletes. The key is for practitioners/coaches to be more vigilant in monitoring the athlete's training responses during the heat acclimation sessions (ensuring they're not working too hard during the session due to their greater propensity for thermal strain), ensure coaches are managing the overall training load during that time as heat acclimation work can be quite fatiguing, and monitoring hydration throughout the acclimation period to ensure they're not progressively dehydrating.

Ben Stephenson, PhD Candidate, Loughborough University

5.5 HYDRATION FOR THE PARA ATHLETE

The athlete's ability to maintain an appropriate hydration level throughout the day and during an exercise bout is important for maintaining well-being and optimising exercise performance (Cheuvront and Kenefick 2012; McDermott et al. 2017; Shirreffs and Sawka 2011). This includes prevention of both extremes of hydration – dehydration (or hypohydration) and overhydration (an increased risk of hyponatremia, or low plasma sodium levels). General sedentary adult fluid intake guidelines are inappropriate for athletes, so educating athletes to understand their own individual fluid needs under differing exercise and environmental conditions is an important role for the sports nutrition practitioner.

5.5.1 Strategies for Assessing Hydration

Commencing exercise in a well-hydrated state is the first step towards optimising performance, especially in sessions undertaken in warm–hot environments. Due to the restricted availability or opportunity to consume fluids during sport, it is not uncommon for able-bodied athletes to develop a fluid deficit over a training session or competition event. While there is a lack of consensus regarding the most accurate assessment of hydration in athletes, the use of two or more of the following indicators of hydration status is optimal when available (Cheuvront and Kenefick 2012; Cheuvront et al. 2010). Urine colour is a good indicator of chronic hydration status, and a variety of urine colour charts (such as www.hydrationcheck.com) are available to assist the athlete with predicting hydration status (McDermott et al. 2017). Urine frequency is another indicator, although this can be influenced by nerves and some medications in Para athletes. For practitioners who have access to a portable urinary refractometer, the measurement of urine specific gravity (USG) on the first urine sample produced each morning can be a useful way of tracking individual hydration status over time and in response to different challenges presented by travel, altitude, heat and competition (Maughan and Shirreffs 2008). A USG <1.020, sometimes ranging to <1.025 due to individual variation, is indicative of euhydration (McDermott et al. 2017). Thirst may also be a good predictor or hydration status at rest, and when used in combination with other factors.

Figure 5.1 shows the likelihood of dehydration based on two of the following indicators: dark urine colour, thirst and/or body mass loss, and suggests that dehydration is *likely,* whereas the presence of three indicators; dark urine colour,

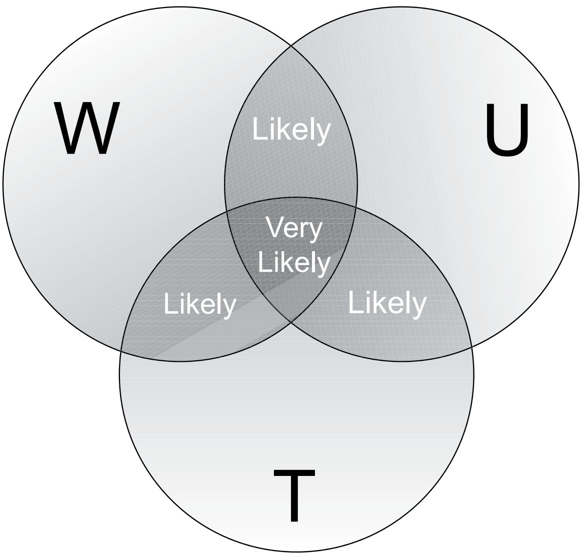


FIGURE 5.1 Presentation of the interaction between three primary indicators of hydration status to assess likelihood of dehydration. (From Cheuvront, S.N. and Sawka, M.N. 2005. *Gatorade Sports Science Institute: Sports Science Exchange* 18:1–5, public domain.)

thirst and body mass loss, suggests that dehydration is *very likely* (Cheuvront and Sawka 2005). Better attention to fluid intake over the day and around training sessions may be required if there is consistent evidence of dehydration.

Overhydration or overzealous rehydration may also be problematic, particularly when this occurs late in the day and disrupts sleep due to the need to urinate during the night. Advice should include planning appropriate fluid intake throughout the day to counter losses, drinking with meals (since the electrolytes and other meal components will assist in fluid retention), and the specific replacement of sweat electrolyte losses (via the use of sports drinks, specific electrolyte preparations or salt-rich foods) when addressing the restoration of large sweat losses (Maughan et al. 1997).

5.5.2 Fluid Needs Before and During Exercise

Sweat losses vary with environmental temperatures in which the sport is played, the exercise intensity, athlete's impairment and the type of clothing the athlete is wearing. Sports that are played exclusively indoors may have less seasonal (summer vs. winter) differences in fluid loss due to the controlled environment (Garth and Burke 2013); therefore, recommendations for fluid intake before and during competition (see Chapter 3) revolve around an individualised fluid plan that is sympathetic to the athlete's expected sweat rates, the opportunity to consume fluids during their event and the consequences associated with either too little or too much fluid intake. Training sessions can be used to collect this information and to develop and practise the individualised hydration plans. The strategy of consuming a bolus of fluid prior to exercise then drinking regularly during the session is likely to be more effective for achieving an appropriate pacing of fluid intake than commencing exercise without fluid and waiting until thirst dictates the need to drink. Indeed, in many sports, practical factors such as restricted access to fluid or gastrointestinal discomfort may prevent an athlete from drinking a sufficient volume of fluid once they have become thirsty (see Chapter 3). In addition to these factors, some athletes with an impairment deliberately avoid consuming fluid prior to or during exercise due to the impracticalities of accessing a bathroom when required or for other reasons. Therefore, training sessions are useful for trialling the timing, volume and type of drinks to be included in the fluid plan before and during exercise to suit the specific practical and physiological needs of the athlete. Keeping a log to track body weight changes during exercise, while accounting for any urinary losses and fluids consumed, may be useful for predicting individual fluid replacement needs in different environmental conditions. Consuming a small salted snack such as pretzels or fluids containing sodium (20–50 mmol/L) before exercise (or both) may help stimulate thirst and retain consumed fluids (Shirreffs and Sawka 2011).

To estimate fluid balance and sweat rates incurred during an exercise bout:

1. Measure body mass both before and after at least 1 hour of exercise under conditions similar to competition or hard training. Vary environmental conditions, terrain, etc., depending on the sport.
2. Measure body mass as accurately as possible by wearing minimal clothing, while barefoot, and preferably without prostheses, strapping and other

sporting equipment. In the case of postexercise measurements, towel-dry the athlete and measure immediately. For wheelchair athletes, where possible, use a set of seated scales.

Example: Preexercise mass = 74.0 kg
Postexercise mass = 72.5 kg
Fluid deficit = 1.5 kg

To convert the fluid deficit to % body mass (BM), divide the deficit by starting body mass and multiply by 100. For example, 1.5 kg/74.0 kg × 100 = 2%

3. Estimate the weight of any fluid or foods consumed during the session (e.g., 1 litre of fluid = 1 kg or 1000 g).
4. Calculate sweat loss by adding the weight of foods/consumed during the session to the fluid deficit: Sweat loss (litres) = body mass before exercise (in kg) − body mass after exercise (kg) + weight of fluids/foods consumed (kg).
   Example: 74.0 kg − 72.5 kg = 1.5 kg fluid deficit + 1.0 kg (fluid) = sweat loss of 2.5 kg or 2500 mL.
   To convert to a sweat rate per hour, divide by the exercise time in minutes and multiply by 60.

Use these calculations to assess how well the athlete hydrated during the session and how much they need to rehydrate afterwards. If they gained mass, more fluid was consumed than lost via sweat and the athlete may need to reduce their fluid intake. If >2% BM was lost, work with the athlete to find ways to consume a greater volume of fluid during exercise.

There are limited reports on sweat rates and fluid intake practises in Para athletes. Black et al. (2013) examined fluid losses and intake in elite wheelchair rugby players over two training sessions and suggested that athletes with quadriplegia ingest fluid volumes that exceed their losses (average sweat loss of 0.17 L/h), resulting in them having plasma sodium levels at the low end of normal range (135–136 mmol/L) over the course of a day where these two practises took place (Black et al. 2013). Similarly, Goosey-Tolfrey et al. (2008a) found fluid intakes in wheelchair tennis players (n = 8, variety of impairments but mostly SCI) exceeded sweat rates in hot conditions (mean sweat rate 648 mL/h, mean fluid intake 1198 mL/h). When cooling strategies were used during the same exercise, fluid intakes better matched sweat rates (mean sweat rate 687 mL/h, mean fluid intake 700 mL/h). Several studies have showed overconsumption of fluids during exercise in athletes with very low sweat rates, such as quadriplegics, likely driven by elevated core temperature (Griggs et al. 2015a; Moran 2012). This highlights the importance of athletes knowing their fluid intake needs and finding ways to control core temperature during exercise (see cooling recommendations) and for additional sodium during exercise (Black et al. 2013).

5.5.3 Fluid Needs After Exercise

Replacing the fluid and electrolytes lost as sweat is an important component of postexercise recovery, especially when the losses are substantial, the environment is hot and preparation time for the next session is relatively short. Since a rehydration plan will also need to address ongoing sweat and urine losses, restoration of fluid balance in the hours after exercise will require the individual to consume a fluid volume equivalent to ~125%–150% of the deficit created by the exercise bout. Replacement of sweat sodium losses contributes to rehydration goals by preserving thirst and by minimising urine losses (Evans et al. 2017; Maughan et al. 1997). This can be achieved by choosing sodium-containing fluids (such as milk or sports drinks) or by consuming water with a meal or snack that includes foods that are salt-containing (such as bread, cheese, many breakfast cereals, yeast-extract spreads) or have additional salt added to them in their preparation (such as eggs and most main meals). There is limited evidence to support avoidance of caffeinated beverages before or after exercise from a hydration perspective (Zhang et al. 2015); however, beverages with more than 2% alcohol per volume should be avoided as they induce additional fluid losses (Evans et al. 2017).

COMMENTARY BOX 5.3

COACH'S INSIGHT: What sports nutrition practises have had the biggest impact on the training capability or performance of your athletes?

> If I had to name just one: having had most of my work focused primarily on strength and power athletes in summer sport profiles, the need for proper hydration is imperative.

Sam Gardner, US Paralympics Strength & Conditioning Coach

5.6 PRACTICAL HYDRATION AND COOLING TIPS FOR THE PARA ATHLETE

- Experiment with cooling strategies to help manage body temperature, especially in hot conditions. Examples include spray bottles of cool water with fans, cold beverages/ice slurries, cooling vests and ice-cold towels around the wrists or neck.
- Ensure athletes understand their individual fluid intake and cooling needs, which may be very different from one individual to another.
- Electrolyte-rich fluids may improve hydration, especially during air travel, in hot and humid conditions and during prolonged exercise of >60 minutes.
- Monitor urine colour, volume and frequency throughout the day. Aim for clear to pale yellow colour with regular urine output through the day to ensure adequate hydration.
- To minimise dehydration in difficult situations (e.g., travel or limited restroom access) and to replenish fluid losses >2% of body weight, choose an electrolyte-rich beverage (e.g., milk, sports drink or electrolyte tablets/powders).

REFERENCES

Black, K.E., Huxford, J., Perry, T. and Brown, R.C. 2013. Fluid and sodium balance of elite wheelchair rugby players. *International Journal of Sports Nutrition and Exercise Metabolism* 23:110–118.

Bongers, C.C.W.G., Thijssen, D.H.J., Veltmeijer, M.T.W., Hopman, M.T.E. and Eijsvogels, T.M.H. 2015. Precooling and percooling (cooling during exercise) both improve performance in the heat: A meta-analytical review. *British Journal of Sports Medicine* 49:377–384.

Broad, E.M. 1998. The effects of heat on performance in wheelchair shooters. *Masters Thesis*, University of Canberra.

Castle, P.C., Kularatne, B.P., Brewer, J. et al. 2013. Partial heat acclimation of athletes with spinal cord lesion. *European Journal of Applied Physiology* 113:109–115.

Cheuvront, S.N., Ely, B.R., Kenfick, R.W. and Sawka, M.N. 2010. Biological variation and diagnostic accuracy of dehydration assessment biomarkers. *American Journal of Clinical Nutrition* 92:565–573.

Cheuvront, S.N. and Kenefick, R.W. 2012. Hydration for recreational sport and physical activity. *Nutrition Reviews* 70(Suppl. 2):S137–S142.

Cheuvront, S.N. and Sawka, M.N. 2005. Hydration assessment of athletes. *Gatorade Sports Science Institute: Sports Science Exchange* 18:1–5.

Cotter, J.D. and Taylor, N.A.S. 2005. The distribution of cutaneous sudomotor and alliesthesial thermosensitivity in mildly heat-stressed humans: An open-loop approach. *Journal of Physiology* 565:335–345.

Davis, S.L., Wilson, T.E., White, A.T. and Frohman, E.M. 2010. Thermoregulation in multiple sclerosis. *Journal of Applied Physiology* 109:1531–1537.

Evans, G.H., James, L.J., Shirreffs, S.M. and Maughan, R.J. 2017. Optimizing the restoration and maintenance of fluid balance after exercise-induced dehydration. *Journal of Applied Physiology* 122:945–951.

Forsyth, P., Pumpa, K., Knight, E. and Miller, J. 2016. Physiological and perceptual effects of precooling in wheelchair basketball athletes. *Journal of Spinal Cord Medicine* 39:671–678.

Garth, A.K. and Burke L.M. 2013. What do athletes drink during competitive sporting activities? *Sports Medicine* 43:539–564.

Goosey-Tolfrey, V., Diaper, N.J., Crosland, J. and Tolfrey, K. 2008a. Fluid intake during wheelchair exercise in the heat: effects of localized cooling garments. *International Journal of Sports Physiology and Performance* 3:145–156.

Goosey-Tolfrey, V., Swainson, M., Boyd, C., Atkinson, G. and Tolfrey, K. 2008b. The effectiveness of hand cooling at reducing exercise-induced hyperthermia and improving distance-race performance in wheelchair and able-bodied athletes. *Journal of Applied Physiology* 105:37–43.

Griggs, K.E., Havenith, G., Paulson, T.A.W., Price, M.J. and Goosey-Tolfrey, V.L. 2017. Effects of cooling before and during simulated match play on thermoregulatory responses of athletes with tetraplegia. *Journal of Science and Medicine in Sport* 20:819–824.

Griggs, K.E., Leicht, C.A., Price, M.J. and Goosey-Tolfrey, V.L. 2015a. Thermoregulation during intermittent exercise in athletes with a spinal-cord injury. *International Journal of Sports Physiology and Performance* 10:469–475.

Griggs, K.E., Price, M.J. and Goosey-Tolfrey, V.L. 2015b. Cooling athletes with a spinal cord injury. *Sports Medicine* 45:9–21.

Maughan, R.J., Leiper, J.B. and Shirreffs, S.M. 1997. Factors influencing the restoration of fluid and electrolyte balance after exercise in the heat. *British Journal of Sports Medicine* 31:175–182.

Maughan, R.J. and Shirreffs, S.M. 2008. Development of individual hydration strategies for athletes. *International Journal of Sport Nutrition and Exercise Metabolism* 18:457–472.

McDermott, B.P., Anderson, S.A., Armstrong, L.E. et al. 2017. National Athletic Trainers' Association Position Statement: Fluid replacement for the physically active. *Journal of Athletic Training* 52:877–895.

Moran, S. 2012. Fluid balance in Australian wheelchair rugby athletes. *Medicine and Science in Sports and Exercise* 44(Suppl. 2):1200.

Moore, A. 2018. Effects of pre-exercise ice slurry ingestion on physiological and perceptual measures in athletes with spinal cord injuries. *Masters Thesis*, Central Washington University.

Periard, J.D., Racinais, S. and Sawka, M.N. 2015. Adaptations and mechanisms of human heat acclimation: Applications for competitive athletes and sports. *Scandinavian Journal of Medicine and Science in Sports* 25(Suppl. 1):20–38.

Price, M.J. 2006. Thermoregulation during exercise in individuals with spinal cord injuries. *Sports Medicine* 36:863–879.

Pritchett, R.C., Al-Nawaiseh, A.M., Pritchett, K.L., Nethery, V., Bishop, P.A. and Green, J.M. 2015. Sweat gland density and response during high intensity exercise in athletes with spinal cord injuries. *Biology of Sport* 32:249–254.

Pritchett, R.C., Bishop, P.A., Yang, Z. et al. 2010. Evaluation of artificial sweat in athletes with spinal cord injuries. *European Journal of Applied Physiology* 109:125–131.

Racinais, S., Alonso, J.M., Coutts, A.J. et al. 2015. Consensus recommendations on training and competing in the heat. *British Journal of Sports Medicine* 49:1164–1173.

Ross, M., Abbiss, C., Laursen, P., Martin, D. and Burke, L. 2013. Precooling methods and their effects on athletic performance. *Sports Medicine* 43:207–225.

Scaramella, J., Kirihennedige, N. and E. Broad. 2018. Key nutritional strategies to optimize performance in Para athletes. *Physical Medicine and Rehabilitation Clinics of North America* 29:283–298.

Shirreffs, S.M. and M.N. Sawka. 2011. Fluid and electrolyte needs for training, competition, and recovery. *Journal of Sports Science* 29(S1):S39–S46.

Trbovich, M.B., Kiratli, J.B. and Price, M.J. 2016. The effects of a heat acclimation protocol in persons with spinal cord injury. *Journal of Thermal Biology* 62:56–62.

Trbovich, M., Ortega, C., Schroeder, J. and Fredrickson, M. 2014. Effect of a cooling vest on core temperature in athletes with and without spinal cord injury. *Topics in Spinal Cord Injury Rehabilitation* 20:70–80.

Webborn, N., Price, M.J., Castle, P. and Goosey-Tolfrey, V.L. 2005. Effects of two cooling strategies on thermoregulatory responses of tetraplegic athletes during repeated intermittent exercise in the heat. *Journal of Applied Physiology* 98:2101–2017.

Webborn, N., Price, M.J., Castle, P. and Goosey-Tolfrey, V.L. 2010. Cooling strategies improve intermittent sprint performance in the heat of athletes with tetraplegia. *British Journal of Sports Medicine* 44:455–460.

Zhang, Y., Coca, A., Casa, D.J., Antonio, J., Green, J.M. and Bishop, P.A. 2015. Caffeine and diuresis during rest and exercise: A meta-analysis. *Journal of Science and Medicine in Sport* 18:569–574.

6 Spinal Cord Injuries

Victoria Goosey-Tolfrey,
Terri Graham-Paulson and Mike Price

CONTENTS

6.1 INTRODUCTION

Nutrition recommendations currently used in sport for those with an impairment are primarily based upon data from able-bodied (AB) athletes (as outlined in Chapter 3), but these are almost certainly not directly transferable to athletes with a spinal cord injury (SCI). Both metabolic and physiological functions are altered in individuals with a SCI. For example, the level and completeness of injury (described in the following section) are known to influence drug pharmacokinetics (Mestre et al. 2011) and caffeine absorption (Graham-Paulson et al. 2017). Physiologically, there are many differences between upper- and lower-body exercise, as generally experienced by athletes with SCI and AB athletes, respectively. Given the smaller working muscle mass used by an athlete with SCI during wheelchair propulsion, there are clearly lower energy requirements compared to those of AB athletes in equivalent sports (Price 2010). Furthermore, as a consequence of the SCI there may be considerable muscle atrophy in the lower limbs, leading to a lower resting metabolic rate (RMR) and, in turn, a further reduction in daily energy expenditure (EE). To prevent unwanted weight gain, energy intake must be correspondingly reduced. Consequently, a number of intriguing questions centre on the physiology of individuals with SCI, particularly in relation to EE, energy requirements and performance, all of which will be discussed in this chapter. For the purpose of this chapter, spinal cord injuries include spina bifida and traumatic and nontraumatic spinal cord lesions.

Para-sports that are open to persons with a SCI are listed in Table 6.1. To enable fair competition, athletes are classified based on the location of lesions of the spinal cord and their association with the physical impairment and functionality. Over the years, this has become sport-specific, and in the case of athletics, this is managed by the International Paralympic Committee (IPC) (see Table 6.2). The reader is guided to the IPC website (IPC 2018) for guidance on other sports, as the classification for some is managed by other organisations (e.g., International Wheelchair Rugby Federation [IWRF]).

6.2 SPINAL CORD INJURY

The spine has two main components: the spinal column and the spinal cord. To understand the classification system for athletes with SCI in sport, the anatomy of different regions of the column and any resultant loss of function must be understood. There are 33 vertebrae which are divided into five types: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral and 4 coccygeal, and referred to by a letter and numerical code (e.g., T1–T12 for the thoracic vertebrae). The spinal cord, which is divided into 31 segments, determines the main muscles that are innervated through the motor nerves. In brief, thoracic or lumbar spinal cord injuries cause functional loss in the legs and trunk muscles/organs innervated below the level of lesion (paraplegia), while cervical spinal cord injuries cause functional loss in all four extremities (quadriplegia), with the degree of dysfunction approximately proportional to the level of lesion (Janssen and Hopman 2005). Paraplegia and quadriplegia are typically caused by an injury to the spinal cord, with the resultant level of the injury determining the extent of the motor loss, which can vary from impaired function to complete muscle group or limb paralysis. The SCI may also be complete or incomplete. A complete injury will mean loss of all function, motor and sensory, below the level of the injury. An incomplete lesion is one where there is neurological function below the level of the injury whereby there may be complete motor loss but incomplete sensory loss, or vice versa. There may also be a combination of sensory impairments where, for example, the spinothalamic tracts are injured, resulting in loss of pain and temperature sensation, but the dorsal columns are preserved with normal light touch and position sense. Figure 6.1, taken from the American Spinal Injury Association (ASIA) classification manual, details the sensory and motor impairments likely to occur along the spinal cord.

TABLE 6.1
Paralympic Sports Open to People with Spinal Cord Injury

Sport	Wheelchair	Quadriplegic	Paraplegic
	Summer		
Archery	√	▲	▼
Para athletics*	√	▲	▼
Badminton*	√	▲	▼
Canoe	○	▲	▼
Cycling	○	▲	▼
Equestrian		▲	▼
Para powerlifting			▼
Rowing		▲	▼
Shooting Para sport	√	▲	▼
Sitting volleyball			▼
Para swimming		▲	▼
Table tennis	√	▲	▼
Triathlon	√	▲	▼
Wheelchair basketball*	√		▼
Wheelchair fencing	√	▲	▼
Wheelchair rugby*	√	▲	
Wheelchair tennis*	√	▲	▼
	Winter		
Para alpine skiing	○	▲	▼
Para biathlon	○		▼
Para cross-country skiing	○		▼
Para ice hockey	○	▲	▼
Wheelchair curling	√	▲	▼

Source: Adapted from Tweedy, S. and Diaper, N. 2010. In *Wheelchair Sport*, ed. Goosey-Tolfrey, V. pp. 3–28. Champaign, IL: Human Kinetics.
√ Wheelchair sport.
* Manual propelled sports chair.
○ Assistive device or adapted version of a wheelchair used, where wheels are replaced by ski, canoe seat or skis/blades for travel on water/ice/snow.
▲ Open to individuals with SCI, with quadriplegia.
▼ Open to individuals with SCI, with paraplegia.

6.2.1 Physiological Adaptations Following a Spinal Cord Injury

Spinal cord injury results in a reduction of physical work capacity, as shown by variables such as peak oxygen uptake ($\dot{V}O_{2peak}$), synonymous with maximal oxygen uptake ($\dot{V}O_{2max}$) in AB athletes, and maximal power output. The reduction in functional capacity is generally considered to be due to the reduced muscle mass as a result of paralysis and the reduced sympathetic nervous system (SNS) activity

TABLE 6.2
Spinal Cord Injury Classification Categories within Wheelchair Track Events

Class	Description	Typical Track Events	Rio 2016
T51	Athletes usually have decreased shoulder muscle power and difficulty straightening the elbows for a pushing action required for wheelchair racing propulsion. There is no muscle power in the trunk. Wheelchair propulsion is achieved with a pulling action using the elbow flexor and wrist extensor muscles.	100 m≫	100 m ≫, 400 m ≫
T52	Athletes use their shoulder, elbow and wrist muscles for wheelchair propulsion. There is poor to full muscle power in the fingers with wasting of the intrinsic muscles of the hands. Muscle power in the trunk is typically absent.	100 m, 200 m, 400 m, 800 m ≫	100 m, 400 m, 800 m ≫, marathon ≫
T53	Athletes typically have full function of the arms but no abdominal or lower spinal muscle activity (grade 0).	100 m, 200 m, 400 m, 800 m ≫	100 m, 400 m, 800 m, 1500 m ≫, 5000 m ≫, marathon ≫, 4 × 400 m relay
T54	Athletes have full upper muscle power in the arms and some to full muscle power in the trunk. Athletes may have some function in the legs.	100 m, 200 m, 400 m, 800 m, 1500 m, 5000 m, marathon	100 m, 400 m, 800 m, 1500 m, 5000 m, marathon, 4 × 400 m relay

Source: Adapted from information derived from https://www.paralympic.org/athletics/classification.
Note: Each sport will have a different sport-specific classification system and the reader is guided to the International Paralympic Committee (IPC) website for up-to-date information https://www.paralympic.org/classification-of-sports.
≫ Competitors in this classification may take part in an event for the next competed classification, for example, T53 may compete in T54 1500 m etc.

below the level of lesion. Indeed, measures from standard laboratory-based tests for aerobic capacity are reduced in proportion to the lesion level. For example, athletes with quadriplegia demonstrate the lowest values for $\dot{V}O_{2peak}$ (1.67 ± 0.38 vs. 2.47 ± 0.33 L/min) and peak heart rate (129 ± 12 vs. 184 ± 10 beats/min) when compared to athletes with paraplegia (Leicht et al. 2012), the latter being due to the complete loss of SNS activity in quadriplegia and subsequently the cardioaccelerator nerves innervated between T1 and T4. For athletes with lower-level paraplegia (e.g., T7 and below), peak heart rate can be similar to that observed for upper-body-trained AB and non-SCI wheelchair athletes (~180–190 beats/min), but with lower $\dot{V}O_{2peak}$ values (2.47 L/min vs. 3.35 L/min, for SCI and non-SCI wheelchair athletes, respectively; Leicht et al. 2012). Although laboratory-based measures can be obtained for athletes with SCI, those athletes

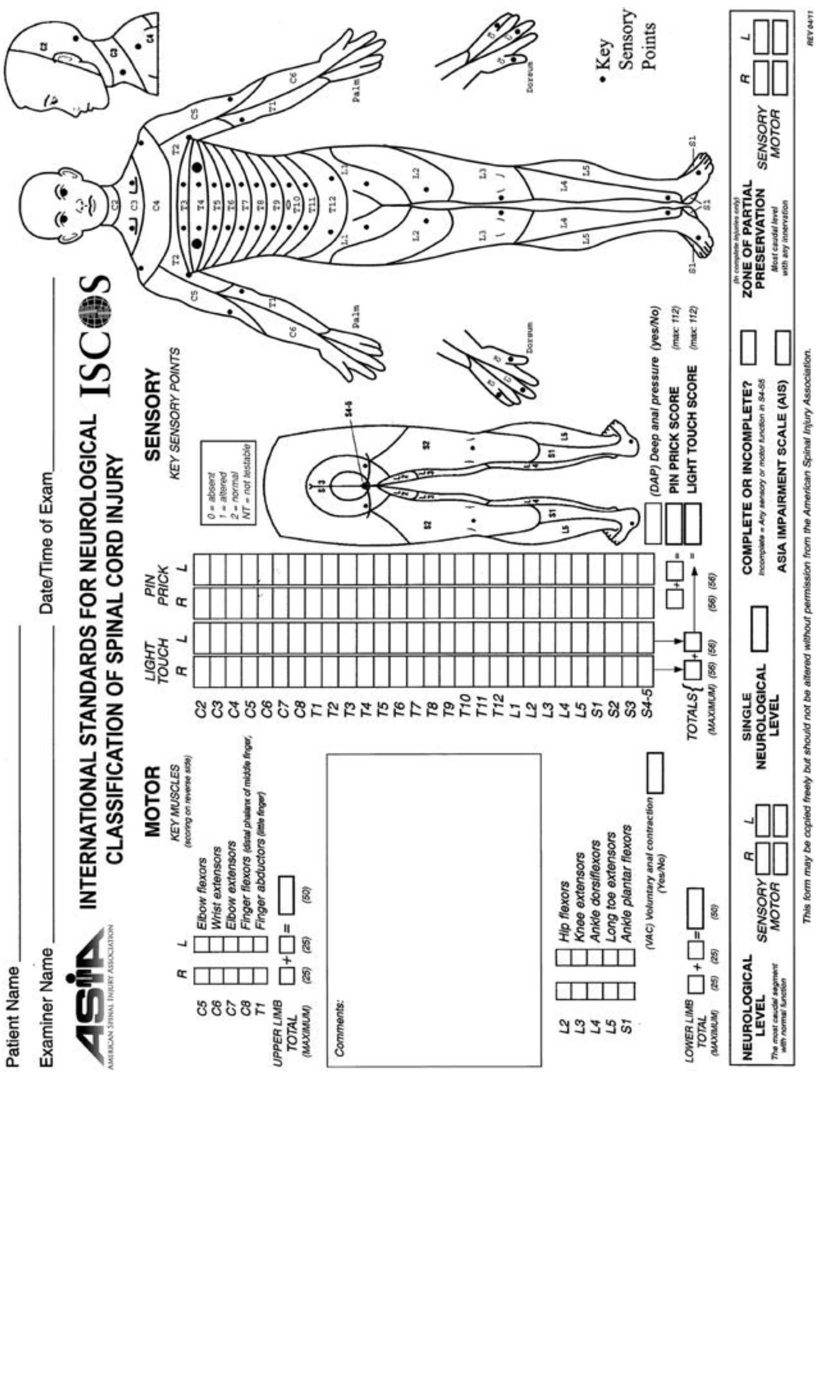


FIGURE 6.1 The American Spinal Injury Association (ASIA) standards for neurological classification of SCI worksheet. (From American Spinal Injury Association 2011. *International Standards for Neurological Classification of Spinal Injury*, Atlanta, GA.)

(Continued)

Muscle Function Grading

0 = total paralysis

1 = palpable or visible contraction

2 = active movement, full range of motion (ROM) with gravity eliminated

3 = active movement, full ROM against gravity

4 = active movement, full ROM against gravity and moderate resistance in a muscle specific position.

5 = (normal) active movement, full ROM against gravity and full resistance in a muscle specific position expected from an otherwise unimpaired person.

5* = (normal) active movement, full ROM against gravity and sufficient resistance to be considered normal if identified inhibiting factors (i.e. pain, disuse) were not present.

NT = not testable (i.e. due to immobilisation, severe pain such that the patient cannot be graded, amputation of limb or contracture of >50% of the range of motion).

ASIA Impairment (AIS) Scale

☐ **A = Complete.** No sensory or motor function is preserved in the sacral segments S4-S5.

☐ **B = Sensory Incomplete.** Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5 (light touch, pin prick at S4-S5: or deep anal pressure (DAP)), AND no motor function is preserved more than three levels below the motor level on either side of the body.

☐ **C = Motor Incomplete.** Motor function is preserved below the neurological level**, and more than half of key muscle functions below the single neurological level of injury (NLI) have a muscle grade less than 3 (Grades 0-2).

☐ **D = Motor Incomplete.** Motor function is preserved below the neurological level**, and at least half (half or more) of key muscle functions below the NLI have a muscle grade ≥ 3.

☐ **E = Normal.** If sensation and motor function as tested with the ISNCSCI are graded as normal in all segments, and the patient had prior deficits, then the AIS grade is E. Someone without an initial SCI does not receive an AIS grade.

**For an individual to receive a grade of C or D, i.e. motor incomplete status, they must have either (1) voluntary anal sphincter contraction or (2) sacral sensory sparing with sparing of motor function more than three levels below the motor level for that side of the body. The Standards at this time allows even non-key muscle function more than 3 levels below the motor level to be used in determining motor incomplete status (AIS B versus C).

NOTE: When assessing the extent of motor sparing below the level for distinguishing between AIS B and C, the ***motor level*** on each side is used; whereas to differentiate between AIS C and D (based on proportion of key muscle functions with strength grade 3 or greater) the ***single neurological level*** is used.

Steps in Classification

The following order is recommended in determining the classification of individuals with SCI.

1. Determine sensory levels for right and left sides.
2. Determine motor levels for right and left sides.
   Note: in regions where there is no myotome to test, the motor level is presumed to be the same as the sensory level, if testable motor function above that level is also normal.
3. Determine the single neurological level.
   This is the lowest segment where motor and sensory function is normal on both sides, and is the most cephalad of the sensory and motor levels determined in steps 1 and 2.
4. Determine whether the injury is Complete or Incomplete.
   (i.e. absence or presence of sacral sparing)
   If voluntary anal contraction = **No** *AND all S4-5 sensory scores =* **0** *AND deep anal pressure =* **No,** *then injury is COMPLETE. Otherwise, injury is incomplete.*
5. Determine ASIA Impairment Scale (AIS) Grade:

Is injury Complete? If **YES,** AIS=A and can record ZPP (lowest dermatome or myotome on each side with some preservation)

NO ↓

Is injury motor Incomplete? If **NO**, AIS=B (Yes=voluntary anal contraction OR motor function more than three levels below the motor level on a given side, if the patient has sensory incomplete classification)

YES ↓

Are at least half of the key muscles below the single neurological level graded 3 or better?

NO ↓ AIS=C

YES ↓ AIS=D

If sensation and motor function is normal in all segments, AIS=E
Note: AIS E is used in follow-up testing when an individual with a documented SCI has recovered normal function. If at initial testing no deficits are found, the individual is neurologically intact; the ASIA Impairment Scale does not apply.

FIGURE 6.1 (Continued) The American Spinal Injury Association (ASIA) standards for neurological classification of SCI worksheet. (From American Spinal Injury Association 2011. *International Standards for Neurological Classification of Spinal Injury*, Atlanta, GA.)

with a reduced range of heart rate values (i.e., athletes with quadriplegia) may find that the use of heart rate as a measure of exercise intensity is inappropriate. Here, other intensity indicators such as ratings of perceived exertion may be more practical (Goosey-Tolfrey and Price 2010; Paulson et al. 2013; van der Scheer et al. 2018).

As a result of SCI, there are considerable changes in body composition due to muscle wastage below the level of lesion, alongside bone demineralisation and joint deterioration (Jacobs and Nash 2004). Several researchers have used AB age-matched reference values for comparative purposes and noted lower lean mass in the SCI groups (Sutton et al. 2009). Longitudinal work using segmental body composition analysis has shown that lean mass in the upper body increases by up to 15% during the first year after onset of SCI due to intensive rehabilitation (Wilmet et al. 1995). Although the absolute lean mass in the upper limbs of sedentary individuals with paraplegia is similar to that in the AB population (Spungen et al. 2000, 2003), in a wheelchair sporting context, lean mass of the upper body is actually greater than that of an AB cohort (Sutton et al. 2009). Figure 6.2a shows an example of the body composition taken from a dual-energy x-ray absorptiometry (DXA) scan for a male athlete with SCI (T7, incomplete lesion). The scan highlights that:

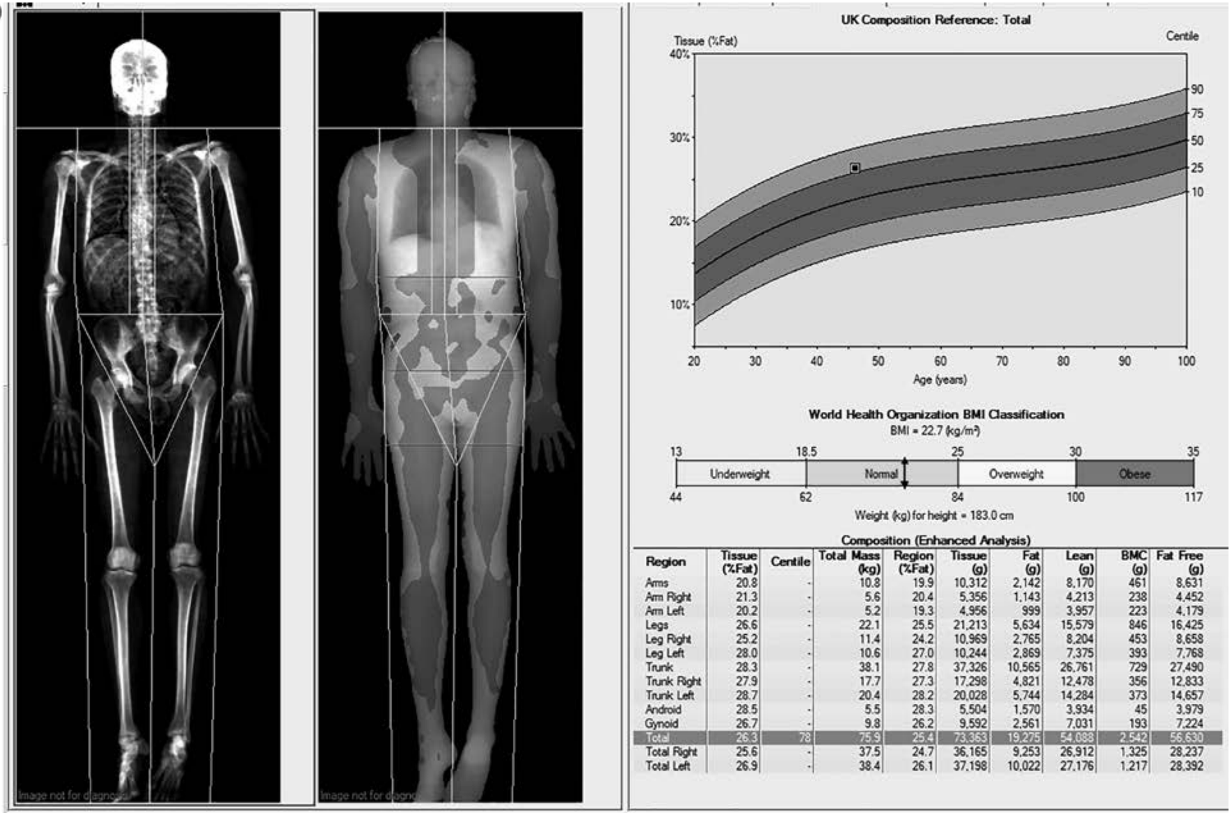
Wheelchair use combined with high-level sport participation results in an improved lean tissue component of the upper body.

Whole-body DXA values mask regional differences, suggesting that the lower fat mass seen in the upper limbs in athletes with SCI offsets the greater fat mass in the lower limbs.

If this was to be compared to an age-matched AB, then the athlete with SCI will have a lower bone mineral density (BMD) and lean mass (Figure 6.2b). They are also likely to have a corresponding greater percentage fat evident in the lower limbs, reflecting bone demineralisation and atrophy of the lower-limb musculature (Figure 6.2a).

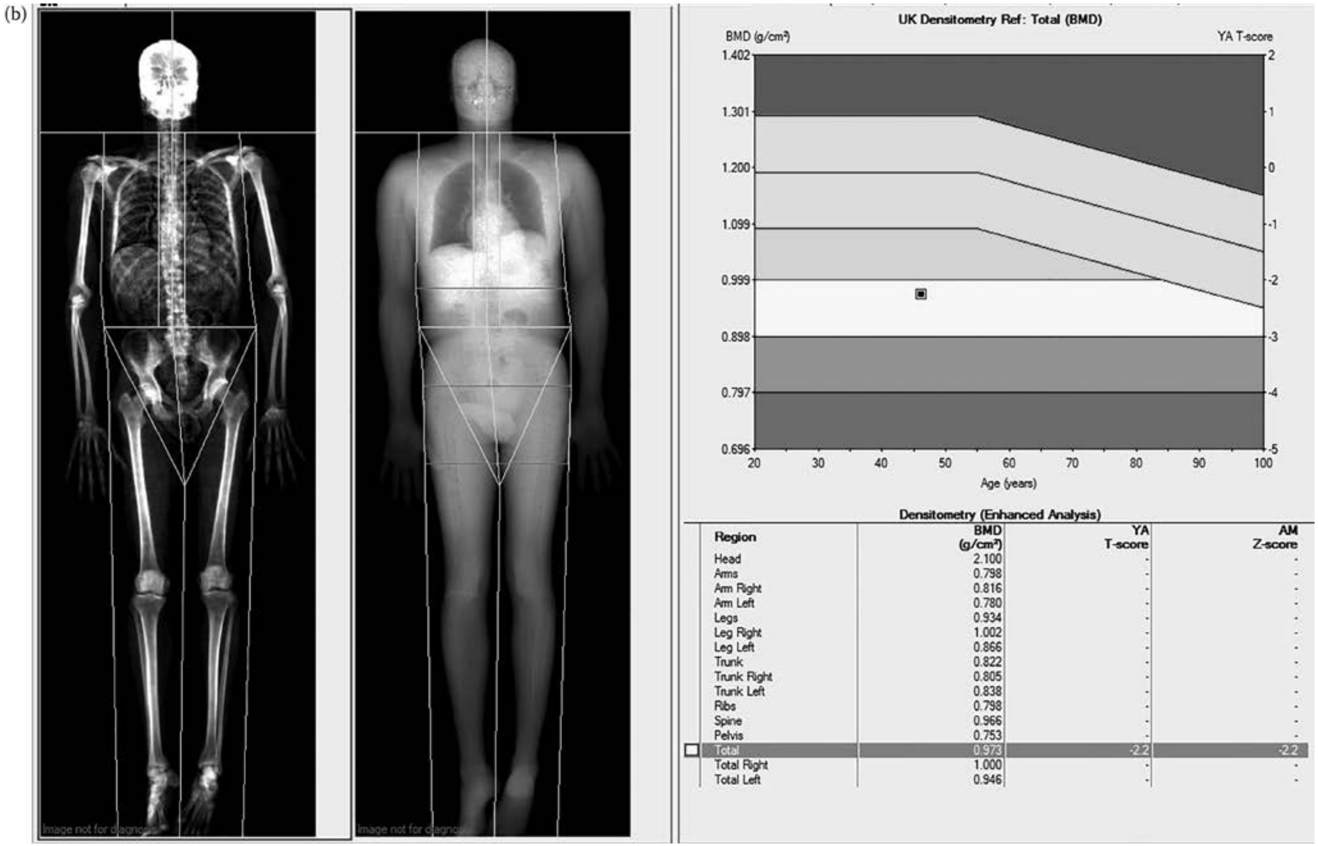
There are several methods that practitioners can use for the estimation of body fat (%fat) and BMD in athletes with SCI, including skinfolds, bioelectrical impedance analysis (BIA), air displacement plethysmography (ADP) and DXA. However, they must be used with caution since skinfolds, BIA and ADP typically underestimate %fat when standard equations developed on able-bodied populations are used (Goosey-Tolfrey et al. 2016). DXA has shown to be a highly reproducible technique in the estimation of total and regional body composition of wheelchair basketball players, provided the presentation of the athlete is standardised and the technical staff are familiar with working with this sample (Keil et al. 2016). That said, it is important that the technician be skilled with working with persons with SCI, who display body asymmetries, may experience spasms and need positioning appropriately on the DXA scanning bed (Goosey-Tolfrey and Sutton 2012). The reader is directed to Section 6.3.2 for further discussion on BMD and vitamin D and Chapter 13 for methods for the assessment of body composition.

(a)



Region	Tissue (%Fat)	Centile	Total Mass (kg)	Region (%Fat)	Tissue (g)	Fat (g)	Lean (g)	BMC (g)	Fat Free (g)
Arms	20.8	-	10.8	19.9	10,312	2,142	8,170	461	8,631
Arm Right	21.3	-	5.6	20.4	5,356	1,143	4,213	238	4,452
Arm Left	20.2	-	5.2	19.3	4,956	999	3,957	223	4,179
Legs	26.6	-	22.1	25.5	21,213	5,634	15,579	846	16,425
Leg Right	25.2	-	11.4	24.2	10,969	2,765	8,204	453	8,658
Leg Left	28.0	-	10.6	27.0	10,244	2,869	7,375	393	7,768
Trunk	28.3	-	38.1	27.8	37,326	10,565	26,761	729	27,490
Trunk Right	27.9	-	17.7	27.3	17,298	4,821	12,478	356	12,833
Trunk Left	28.7	-	20.4	28.2	20,028	5,744	14,284	373	14,657
Android	28.5	-	5.5	28.3	5,504	1,570	3,934	45	3,979
Gynoid	26.7	-	9.8	26.2	9,592	2,561	7,031	193	7,224
Total	26.3	78	75.9	25.4	73,363	19,275	54,088	2,542	56,630
Total Right	25.6	-	37.5	24.7	36,165	9,253	26,912	1,325	28,237
Total Left	26.9	-	38.4	26.1	37,198	10,022	27,176	1,217	28,392

FIGURE 6.2 (a) Dual-energy x-ray absorptiometry (DXA) scan of a male aged 46 years with a spinal cord injury (T7 incomplete), which includes the segmental and total body measures of percent fat. (*Continued*)



Region	BMD (g/cm²)	YA T-score	AM Z-score
Head	2.100	-	-
Arms	0.798	-	-
Arm Right	0.816	-	-
Arm Left	0.780	-	-
Legs	0.934	-	-
Leg Right	1.002	-	-
Leg Left	0.866	-	-
Trunk	0.822	-	-
Trunk Right	0.805	-	-
Trunk Left	0.838	-	-
Ribs	0.798	-	-
Spine	0.966	-	-
Pelvis	0.753	-	-
Total	0.973	-2.2	-2.2
Total Right	1.000	-	-
Total Left	0.946	-	-

FIGURE 6.2 (Continued) (b) bone density segmental and total values for the same athlete. Permission obtained from the athlete.

COMMENTARY BOX 6.1

EXPERT COMMENTARY: Muscle atrophy and the risk of insulin resistance in spinal cord–injured individuals (Dr Luc van Loon, Maastricht University)

When you do muscle biopsies on denervated muscle (vastus lateralis) in paraplegics, you find a few interesting things:

- Although there is muscle atrophy in both Type 1 and 2 muscle fibres, there remain ample satellite cells to allow skeletal muscle hypertrophy. So, if you find ways to stimulate the muscle, you should be able to initiate muscle reconditioning.
- Intramuscular triglyceride (IMTG) stores in denervated muscle of paraplegics are similar to able-bodied individuals – so, there seems to be little excess accumulation of IMTG in the denervated muscle of healthy, active SCI individuals, despite a reduced muscle fibre oxidative capacity.
- The changes in muscle oxidative capacity and mitochondrial function occur mostly in the subsarcolemmal region compared to the intermyofibrillar regions.
- There is a shift in muscle fibre type distribution, with reduced Type 1 muscle fibres and increased Type 2 fibres in the paraplegic individuals compared to able-bodied controls.

Overall, this means that the changes in muscle fibre composition induced by denervation were different from those seen in insulin resistance or Type 2 diabetes.

6.2.2 Energy Expenditure

One of the most important factors contributing to the difference in energy requirements of AB and athletes with SCI is the fact that a smaller working muscle mass is used during everyday and sporting movements (Glaser 1985). A second factor generally accepted to be of importance to EE is the amount of SNS available for exercise. The SNS relates to the "fight or flight" responses of the body to stressful situations, particularly the use of carbohydrate and fat in metabolism. With respect to the SNS, physiologically we are concerned with the amount of adrenaline (epinephrine) and noradrenaline (norepinephrine) released. It is well known that, when compared to AB persons, those with SCI can have a reduced production of these catecholamines (Schmid et al. 1998; Steinberg et al. 2000). More specifically, those with quadriplegia and high-level paraplegia (T1–T5) often have a reduced response, especially for adrenaline, when compared to those with lower-level paraplegia (T6 and below). Furthermore, there is likely to be a wide range of energy requirements in athletes with SCI based on the onset and nature of the level and completeness of the spinal cord injury. In cases where a wheelchair is used for daily mobility, there may be considerable muscle atrophy in the lower limbs, and consequently it would seem reasonable to assume that the daily EE would be lower in persons with SCI.

6.2.2.1 Resting Energy Expenditure

Resting (or basal) energy expenditure can be estimated through the use of prediction equations or normative tables. The majority of prediction equations, which are predominantly generated from AB data, overestimate energy expenditure values for both adults (Alexander et al. 1995; Monroe et al. 1998) and children with SCI (Liusuwan et al. 2004; Patt et al. 2007) being up to, and in some cases, over 30% greater than measured values (Buchholz and Pencharz 2004; Nightingale and Gorgey 2018). For example, Liusuwan et al. (2004) reported 24 h resting EE of ~7850 kJ (1870 kcal)/day for patients with SCI (C6-L3) compared to ~9930 kJ (2365 kcal)/day for age-matched able-bodied controls. This level of error is most likely due to differences in muscle mass and body composition between AB and SCI populations. Recently, factors such as DXA-derived fat free mass have been included within the generation of new prediction equations in patient populations with varying success (Chun et al. 2017; Nightingale and Gorgey 2018). Recently, data for a SCI athlete population (n = 7; T3/4–L3/4/5) and matched able-bodied control group showed no differences between measured (6437 vs. 6964 kJ/day, respectively) and predicted resting EE in most equations that utilised lean tissue mass (Pelly et al. 2018). However, when resting EE was adjusted for lean tissue mass, resting EE values were greater than for AB controls (146 vs. 125 kJ/kg). The reason for greater values was partly due to lean tissue mass being lower in the athletes with SCI but also the potential effect of lesion level in relation to the proportional contribution of the viscera and lower body to RMR altering with different lesion levels. The authors suggested that existing resting EE prediction equations for athletes may require modification in relation to level and completeness of SCI (Pelly et al. 2018).

6.2.2.2 Exercise Energy Expenditure

Where sporting activities are concerned, there are a range of normative values available for AB sports from which EE can be predicted (e.g., McArdle et al. 2000). Although there are fewer predictive values available for wheelchair sports and activities, these normative values are becoming more specific as more research is undertaken in this area. For example, Ainsworth et al. (2000) and Collins et al. (2010) provided a range of EE values for wheelchair-based activities in a nonathletic population. Collins et al. (2010) suggested that the standard metabolic equivalent of task (MET) value for SCI wheelchair users should be reduced to 2.7 mL/kg/min rather than the accepted values of 3.5 mL/kg/min. These developments are welcomed but there is still a need for values relating to elite and young athletes to be derived.

The available literature which has examined wheelchair-dependent patients performing activities of daily living (ADL) has suggested that the RMR and total EE are significantly correlated with lesion level (Mollinger et al. 1985). Although this information has helped dietitians to establish the average energy needs of this patient population, it must be borne in mind that many studies are limited by the hospital environment, where activities such as travel outside the hospital are restricted and where there is limited physical activity. In addition, the majority of data is collected from nonathletic populations. Hence, for the individual athlete with SCI within their

FIGURE 6.3 Expired air collection during wheelchair locomotion on a motorised treadmill.

own environment, there may well be significantly different demands of wheelchair locomotion, and the reported EE values may well be exceeded.

Energy expenditure can also be determined at rest or during specific activities by using indirect calorimetry, that is, analysis of expired gasses (Figure 6.3). The use of indirect calorimetry has been considered a feasible and acceptable addition to routine clinical care of SCI patients with potential to improve the accuracy of nutritional interventions (Nevin et al. 2016). However, for many activities, especially competitions, this technique is impractical due to the requirements of using a mouthpiece or wearing a face mask to collect the expired gas and whether telemetry-based systems are available. In these instances, EE of specific activities, such as wheelchair basketball, can also be predicted from laboratory-based exercise tests (Croft et al. 2010). These tests are usually incremental in nature and cover a range of intensities from rest to maximal exercise. The data collected allows for the relationship between heart rate and oxygen consumption, and thus energy expenditure, to be calculated. Heart rate values during the actual activity can then be matched to that obtained in the laboratory test and an equivalent EE value obtained. Not only does this approach enable an overall energy expenditure value to be generated but also the range of exercise intensities of the activity to be evaluated. The latter may be of particular importance for developing training and competition strategies. Predictive methods such as those highlighted above do have potential errors, as values are not obtained from the actual event. For example, the mode of exercise undertaken in the laboratory tests should match the exercise mode and movement pattern of the activity as closely as possible.

The EE and metabolism of athletes with SCI have previously been reviewed (Price 2010). Here, it was noted that the EE of athletes competing in wheelchair sports varied depending upon the mode of exercise and nature of the activity undertaken. As expected, the EE for athletes with SCI was lower than that for the equivalent AB sports and, depending on the sport, was in the range of 26%–85% of AB values. More specifically, the lowest EE values were noted for wheelchair table tennis and wheelchair fencing, which may be considered more static versions of the AB sports. Moreover, wheelchair rugby EE is typically low due to the participants being predominantly those with quadriplegia and demonstrating the lowest available muscle mass for movement. It should be noted, though, that there are now more non-SCI wheelchair players who exhibit greater $\dot{V}O_{2peak}$ values (2.4 vs. 1.4 L/min; Griggs et al. 2017b) and potentially greater exercise EE values. Both wheelchair tennis and basketball exhibited greater EE than wheelchair table tennis and wheelchair fencing, with the wheelchair basketball data being lower than predicted values from McArdle et al. (2000) for full on-court competition. Data from Croft et al. (2010) highlighted that competition standard is important to consider for EE, with elite wheelchair tennis and basketball players demonstrating much greater EE values than for recreational or national-level players (Figure 6.4). Very few studies have reported the difference between male and female

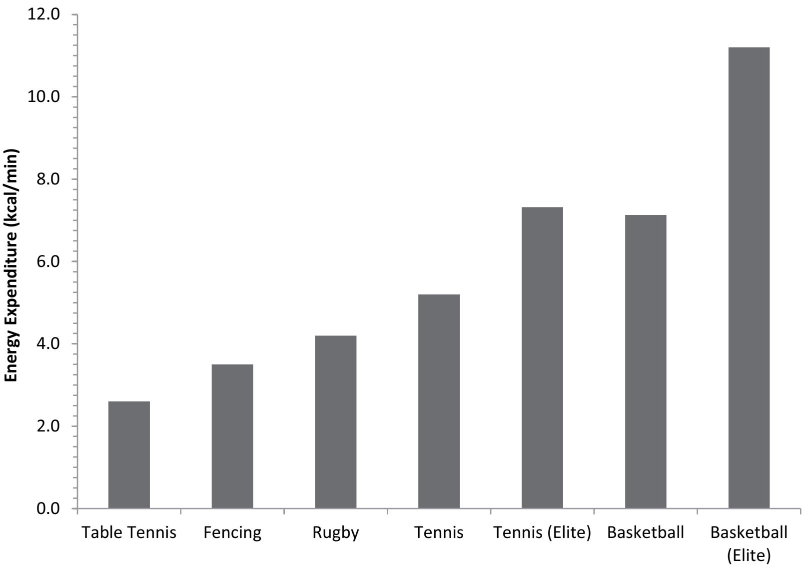


FIGURE 6.4 Energy expenditure for a range of wheelchair sports. Elite data represent international standard athletes for tennis and basketball, respectively (Croft et al. 2010. *International Journal of Sports Physiology and Performance* 5:301–315.). Basketball data (nonelite) are averages for data during a practise session (Burke et al. 1985. *Physician and Sports Medicine* 13:99–102.), competition (Bernardi et al. 1988. *International Journal of Sports Cardiology* 5:58–61.) and basketball training (Abel et al. 2008. *Spinal Cord* 46:785–790.). Tennis data is the average of competitive match play (Roy et al. 2006. *Journal of Strength and Conditioning Research* 20:665–671.) and training sessions (Abel et al. 2008. *Spinal Cord* 46:785–790.). Rugby data is from (Abel et al. 2008. *Spinal Cord* 46:785–790.), whereas fencing and table tennis data are from (Bernardi et al. 1988). *International Journal of Sports Cardiology* 5:58–61.).

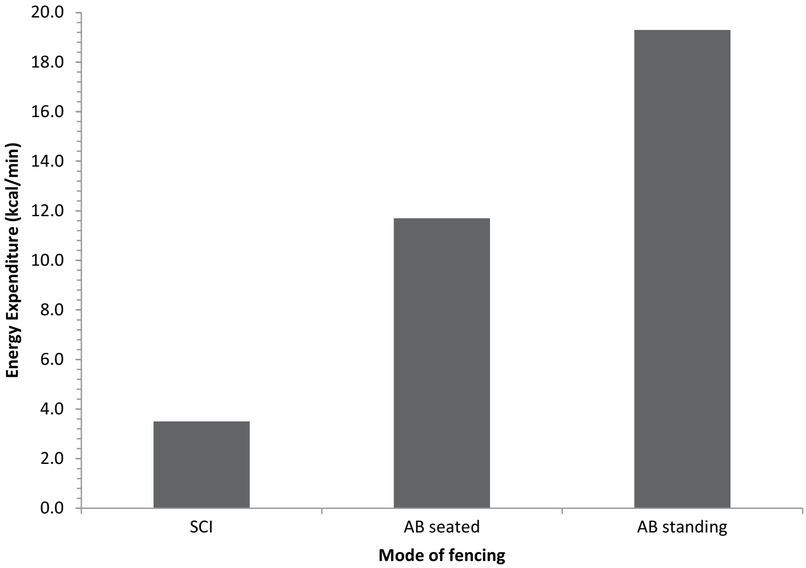


FIGURE 6.5 Energy expenditure for seated and standing fencing compared to wheelchair fencing in athletes with SCI. (Iglesias, X. et al. 2018. *The Journal of Sports Medicine and Physical Fitness*. DOI: 10.23736/S0022-4707.18.08413-X.)

athletes. A recent study on elite male and female wheelchair racers (n = 5) reported a median energy expenditure of 2119 kJ/h (505 kcal/h), with a range of 1608–3020 kJ/h (383–719 kcal/h), during a 25-km field-based time trial (Edwards et al. 2018).

It is important to note that a number of wheelchair sports are not played (or classified) solely on the basis of SCI. For example, the wheelchair versions of basketball, tennis and fencing involve a range of other impairments. Being able to determine EE of a large number of athletes with varying impairments is therefore difficult within a squad of athletes. To illustrate this point, Figure 6.5 demonstrates the differences in EE for wheelchair or seated fencing when compared to conventional fencing, and between wheelchair fencers with and without SCI. The seated and conventional fencing EE data were obtained using AB fencers experienced in playing and coaching wheelchair fencing, thus representing a consistent level of skill (Iglesias et al. 2018). The data for the athletes with SCI is taken from Bernardi et al. (1988). Figure 6.5 clearly shows that within a sport involving different impairments such as seated athletes with SCI compared to those without SCI and likely full or greater muscle mass available, the potential for a wide range of EE values exists.

6.2.3 Gastric Emptying

Among the multitude of factors contributing to successful absorption and assimilation of nutrients is gastric emptying. If gastric emptying is affected by SCI, then the ability to take up nutrients along the intestine may also be affected. Clinically, gastric emptying is slower in patients with high-level SCI compared to those with low-level

SCI (Kao et al. 1999; Lin et al. 2002)- with many (53%–58%) of the patients with SCI tested demonstrating abnormal indices of gastric function after solid meals (Kao et al. 1998, 1999). However, several studies have shown no differences in gastric emptying for both persons with quadriplegia and those with paraplegia compared to AB persons (Lu et al. 1998; Zhang et al. 1994).

It is known from exercise studies of AB individuals that moderate exercise intensities (15 min duration, five-a-side soccer) are sufficient to slow gastric emptying, as does brief high-intensity exercise such as interval training at 66% and 75% $\dot{V}O_{2max}$ (Leiper et al. 2001a,b, 2005). As many wheelchair sports are intermittent in nature and of moderate to high intensity, an already slowed gastric emptying rate as a result of SCI may be accentuated. It is therefore important in sports such as wheelchair racing, triathlon and some team sports whereby the athlete is strapped into their sports chair, often in uncomfortable positions, to ensure sufficient digestion time prior to competition. Athletes should aim to eat small, frequent meals containing energy-dense foods to ensure sufficient total energy is consumed to meet training needs while minimising the risk of gastrointestinal disturbances.

Delayed gastrointestinal transit times may also influence the appearance or absorption of medications and supplements in these individuals. A review of the literature by Mestre et al. (2011) indicated that the delayed absorption seen in some individuals with SCI increased the time to achieve the required therapeutic dose following oral administration. Large interindividual variability in the pattern of caffeine absorption was also reported in individuals with SCI following the consumption of 3 mg/kg/body mass caffeine in capsule format (Graham-Paulson et al. 2017). Hence, dosage and timing recommendations provided to individuals with SCI may need to be adapted from the AB literature. Since SNS and other limiting factors for gastric function are affected by SCI, future work to examine the combined effects of SCI and exercise on gastric emptying and nutrient absorption are encouraged.

6.3 NUTRITIONAL REQUIREMENTS AND BEHAVIOURS

The standards for nutritional requirements used in para sport are generally based on recommendations for AB athletes due to a lack of specific research and guidelines, as outlined in Chapter 3. As discussed previously in this chapter, a number of differences between the two groups do exist, based on severity of SCI, lean mass and sport requirements, which result in a lower resting EE. Caution should therefore be exhibited when adapting or accepting nutritional recommendations developed for AB athletes. As the level of impairment increases from incomplete paraplegia to complete quadriplegia, the energy requirements are reduced given that the amount of available active muscle mass is known to be a key determinant of EE. Reduced energy intakes have been observed in nonathletes (Groah et al. 2009; Levine et al. 1992; Tomey et al. 2005; Walters et al. 2009), semicompetitive or recreational athletes (Potvin et al. 1996; Ribeiro et al. 2005) and elite athletes (Gerrish et al. 2017; Goosey-Tolfrey and Crosland 2010; Krempien and Barr 2011). The daily diets from a variety of elite athletes with SCI report an average energy intake of 6275–12,550 kJ (1500–2300 kcal) (Gerrish et al. 2017; Goosey-Tolfrey and Crosland 2010;

Krempien and Barr 2011). In these studies, carbohydrate intake contributed 3.4–4.4 g/kg body weight, or ~46%–53% of total calories. Protein intake was assessed at 1.0–1.5 g/kg or 15%–20% of calories, with the remaining 28%–37% of calories resulting from dietary fat intake. The macronutrient intakes generally fell within the broad recommendations for the general population but fell short of what would be considered to be the optimal fuel intake to support the training of an elite athlete (as outlined in Chapter 3), in particular the carbohydrate intake. However, these reference values are specific to AB athletes, not those with SCI; hence, the recommendation remains to assess each athlete on an individual basis. Many athletes with SCI monitor and limit dietary intake to help prevent weight gain or to maintain an optimal body composition for their sport (Krempien and Barr, 2012). It is important to ensure that this restriction does not result in poor fuelling and recovery strategies for optimal athletic performance. Further research is needed to examine nutrient intake requirements among elite athletes with SCI.

6.3.1 Macronutrient Requirements

The role of macronutrients to support training and performance in athletes with SCI is not fully understood, with many assumptions that the preferred fuel sources and metabolism of macronutrients are similar to those of AB athletes. Athletes with SCI do have some altered nutrient requirements related to bone health and wound healing (the reader is guided to Chapter 12 for more information).

In AB athletes, the predominant muscle fuel source in lower-intensity exercise is intramuscular triglyceride and free fatty acids. When exercise intensity increases, muscle glycogen and blood glucose become increasingly important fuel sources. As humans have a limited capacity to store muscle and liver glycogen, dietary carbohydrate intake is recommended in some circumstances for athletes to ensure a sufficient availability of glucose for training and competition. In contrast to the limited glycogen stores, fat stores are abundant and a training goal for endurance athletes is often to promote the adaptation of working muscles to increase the capacity to oxidise fat during training. There is no strong evidence that the functional muscle of athletes with SCI will respond in a profoundly different manner than that which has been observed in AB athletes.

6.3.1.1 Carbohydrate Ingestion Before or During Exercise in Athletes with SCI

The ingestion of carbohydrate (CHO) prior to exercise can significantly improve endurance performance (Burke 2015) and the performance of intermittent exercise akin to many team sports (Patterson and Gray 2007; Sugiura and Kobayashi 1998). However, there is surprisingly little literature regarding this aspect in athletes with SCI.

Although the absolute EE of most wheelchair activities in athletes with SCI are lower than for AB athletes, the relative proportions of CHO and fat metabolism appear to be similar, at least in athletes with low- level spinal cord injuries (Jung and Yamasaki 2009; Price 2010). However, little data is available regarding athletes with high-level lesions, where the SNS is often absent and where increases in adrenaline and noradrenaline are potentially lower than for athletes with low-level spinal cord injuries (Schmid et al. 1998; Steinberg et al. 2000). For example, Stallknecht et al. (2001) observed not only lower increases in adrenaline and noradrenaline during 60 min of exercise in persons with spinal cord injury (T1–T5) but also that adipose tissue lipolysis was lower in those with SCI.

Using an AB model, however, Helge (2010) reported higher carbohydrate oxidation and lactate release during arm exercise compared to leg exercise at the same relative load. There also appear to be fewer type I muscle fibres in the arms (triceps brachii/deltoid = 32%–54%) compared to the legs (vastus lateralis/gastrocnemius = 52%–69%) (Killerich et al. 2008; Mizuno et al. 1990; Mygind 1995), and type II muscle fibre area is reported to be larger in the triceps brachii compared to the gastrocnemius (Mizuno et al. 1990). The distribution of muscle fibre type in the arms may be dependent on training status and level of SCI (Gollnick et al. 1972; Schantz et al. 1997), which will in turn influence a person's ability to perform upper-body exercise and the type of substrate utilised (Astorino & Harness 2009; Knechtle et al. 2004). These aforementioned factors highlight that CHO drinks may be of use to many athletes during training and competition, yet athletes anecdotally report avoiding them to prevent weight gain. Hence, education on the demands of exercise and the benefits of CHO drinks may be required for some athletes.

Spendiff and Campbell (2002) examined ingestion of an 8% CHO solution prior to 1 hour of arm crank ergometry followed by a subsequent 20-min performance trial. Performance was improved by 1 km (12.5 vs. 11.5 km) when consuming the CHO solution compared to placebo. Although the athletes tested were upper body–trained AB individuals, the results were similar to those which may be expected for lower-body exercise. In a subsequent study using the same methods, but with wheelchair athletes (predominantly with SCI), Spendiff and Campbell (2003) again observed that the athletes performed significantly better following ingestion of CHO (10.8 km) when compared to the placebo trial (10.2 km). A third study of wheelchair athletes involved a comparison of two different CHO drink concentrations, 4% vs. 11% solution on performance during wheelchair ergometry (Spendiff and Campbell 2005). Both drinks raised blood glucose to similar levels pre-exercise, but there was no difference in wheelchair performance over 20 min (5.1 vs. 5.0 km, respectively) following 60 min of submaximal exercise. However, there was a tendency for the average power output during the time trial to be greater in the 11% CHO trials along with greater blood glucose and respiratory exchange ratio, and lower blood fatty acids. Based on these results, the authors suggested that the 11% solution may be more beneficial for the athletes. Although the evidence suggests that ingestion of CHO 20 min prior to exercise is beneficial to endurance performance, no data has been reported regarding the effects on intermittent sports such as basketball or tennis. Preliminary studies suggest that the ingestion of a CHO-containing drink prior to endurance events provides a beneficial energy source with the potential to improve performance, especially where other pre-exercise feeding is limited (e.g., due to fear of gastrointestinal discomfort). Future work is needed to better understand both the physiological and performance effects of CHO ingestion before and during exercise in individuals with SCI.

The concept and evidence for the benefit of recovery nutrition with the ingestion of carbohydrate-rich foods/fluids along with a moderate amount of protein is well established in AB athletes (as outlined in Chapter 3). At this time, there remains no evidence to suggest that athletes with SCI would not benefit from a recovery nutrition regime. What remains to be determined are the optimal amounts of carbohydrate and protein to support an efficient recovery without exceeding total energy requirements.

6.3.1.2 Protein and Amino Acids

At the present time, there is a dearth of reported literature assessing the protein or amino acid requirements for athletes with SCI. Given this lack of impairment-specific evidence, clinicians and sport scientists continue with the assumption that protein utilisation and requirements to optimise postexercise recovery are similar to current recommendations for AB athletes. Total requirements may be slightly higher if the athlete has a pressure ulcer or wound to support and promote healing (Lee et al. 2006; Reddy et al. 2008). If the athlete has chronic renal insufficiency, the total protein intake should be carefully evaluated to find the balance between what is required to best support training and recovery while not placing any unnecessary burden on the kidneys. Total requirements may also be increased in those who perform resistance training, whereby timely protein synthesis has been shown to enhance adaptations to circuit resistance training (Kressler et al. 2014).

6.3.2 Micronutrient Requirements

There is no evidence at this time to determine whether athletes with SCI have increased micronutrient requirements to support the demands of training and competition. Given this lack of information, the assumption remains that intakes determined for AB data are adequate. The one exception to this is the knowledge that a high incidence of vitamin D insufficiency and deficiency has been observed in those with SCI, with some evidence that poor vitamin D status is prevalent in many athletes with an impairment.

Low BMD associated with acute and chronic SCI is well established (Bauman et al. 1999). While physical activity and weight-bearing activity have been shown to maintain or slightly increase BMD above the injury level (Goktepe et al. 2004), reduced BMD, osteoporosis and fracture risk in the lower limbs remain significant risks (Dauty et al. 2000; de Bruin et al. 2000). One strategy to slow the progression of osteoporosis is to optimise vitamin D status and ensure dietary calcium is adequate. For athletes, a vitamin D receptor in skeletal muscle has been identified, suggesting a role of vitamin D in muscle function and overall strength (Hamilton 2011).

Optimal serum 25(OH) vitamin D (25[OH]D) concentrations remain somewhat controversial, with the following ranges agreed upon for athletes and those with SCI: <25 nmol/L, deficient; 25–50 nmol/L, insufficient; 50–75 nmol/L, suboptimal; and >75 nmol/L, sufficient (Hamilton 2011; Nemunaitis et al. 2010; Oleson et al. 2010). However, Heaney (1999) suggests 25(OH)D concentrations below 80 nmol/L are insufficient, as parathyroid hormone remains upregulated and calcium absorption is somewhat inhibited.

Individuals with SCI are at a considerable risk of suboptimal vitamin D concentrations. The prevalence of vitamin D insufficiency/deficiency is higher in individuals with SCI than in AB populations (range 32%–93%; Flueck and Perret, 2017), and 96% of patients with chronic motor complete SCI (C3-T10) have subtherapeutic levels in the winter months (Oleson et al. 2010). A recent study assessed the vitamin D status of elite Swiss wheelchair athletes and reported 73.2% as insufficient/deficient, whilst those who trained indoors were at greater risk (Flueck et al. 2016). Athletes with SCI appear to be at greatest risk due to a number of factors: immobilisation, lower physical activity levels, bedrest due to complications such as pressure sores, clothing that covers the majority of the skin and indoor training whereby they are not exposed to sufficient sunlight (Flueck et al. 2016). Pritchett et al. (2016) also reported a substantial proportion (41%–51%) of elite Canadian and American Paralympic athletes with SCI to have insufficient vitamin D status in both the winter (February/March) and autumn (October). A seasonal decline in vitamin D status is often observed, yet there was no significant difference between winter and autumn months despite a greater number of athletes reported as sufficient during the autumn compared to the winter (33 vs. 23%, respectively). There was also no significant difference reported between indoor and outdoor sports, yet time spent outdoors was associated with vitamin D status during the autumn. Hence, skin exposure to the sun remains important given that their average vitamin D intake did not meet the Dietary Recommended Intake (DRI) of 600 IU for adults aged 18–70 years.

Some athletes do not appear to be meeting Estimated Average Requirements (EARs) for essential micronutrients for bone health in their daily diets (Gerrish et al. 2017; Krempien and Barr 2011). A three-day dietary recall by elite Canadian athletes with SCI highlighted that >25% of these athletes did not meet EARs for calcium, vitamin D and magnesium, which are important bone health micronutrients (Krempien and Barr 2011). Vitamin and mineral supplementation increased intakes of most nutrients but did not affect prevalence of inadequacy (Krempien and Barr 2011). This is of primary concern given the increased prevalence of poor bone mineralisation and increased risk of fractures (Eser et al. 2005).

A small study of seven adults with SCI showed that a 90-day trial of oral supplementation with 2000 IU of cholecalciferol (vitamin D_3) and 1300 mg of elemental calcium increased vitamin D concentrations to >75 nmol/L with concurrent decreases in parathyroid hormone and no changes to urinary calcium excretion or serum calcium concentrations (Bauman et al. 2011). A sliding scale vitamin D_3 supplementation protocol whereby 15,000 IU/wk, 35,000 IU/wk for 4 wk, 50,000 IU/wk for 8 wk and a continued maintenance dose of 15,000 IU/wk were provided to those with >75 nmol/L, 50–75 nmol/L and <50 nmol/L 25[OH]D, respectively, improved the sufficiency levels in a group of elite Canadian and American Paralympic athletes with SCI from 26% to 91% over a 12–16 week period (Pritchett et al. 2018). It is therefore recommended that athletes with SCI should have their serum 25[OH]D concentrations monitored yearly (ideally at the end of summer) and be provided with oral supplementation of vitamin D_3 as needed to maintain a sufficient vitamin D status.

6.3.3 Additional Nutrients

Dietary fibre intake is consistently reported to be low in both athletes and nonathletes with SCI (Goosey-Tolfrey and Crosland 2010; Krempien and Barr 2011; Walters et al.

2009). Typically, a high-fibre diet with adequate fluid intake is recommended as a strategy for managing bowel routines and function, but depending on the autonomic dysfunction/control of the gastrointestinal tract, this may not be the best approach (Chung and Emmanuel 2006). In one study, increasing dietary fibre by the addition of bran further increased the colonic transit time, suggesting that SCI bowel function may not respond well to additional dietary fibre (Cameron et al. 1996). Recent use of SmartPill technology in adults with SCI has confirmed the safety of this diagnostic tool, and it could be used with athletes who struggle with bowel function (Williams et al. 2012). Bowel habits and function are unique to the athlete, and the risk of stool incontinence has the potential to negatively impact performance during sporting events.

Other nutrient considerations that may require the input of specialist medical knowledge relate to the management of urinary tract infections (UTIs), since there is insufficient evidence that cranberry juice is effective for prevention of UTIs in individuals with SCI (Navarrete-Opazo et al. 2017). Cranberry tablets or dried cranberries (Hess et al. 2008; Burleigh et al. 2013), D-mannose (Kranjcec et al. 2014) and oral probiotics, especially those containing lactobacillus rhamnose and reuteri strains (Beerepoot et al. 2012), are low risk and worth trialling as prophylaxis in those with recurrent UTI. The reader is guided to Chapter 12 for more medical considerations and towards the position statement of the Australian Institute of Sport and the Australian Paralympic Committee (Compton et al. 2015).

COMMENTARY BOX 6.2

COACH'S COMMENTARY: What do you believe are the biggest differences in coaching Para athletes compared to able-bodied athletes? For example, what modifications do you have to make to your training programs and/or coaching style? Does this differ between different impairments?

> In the racing chair, no difference (beyond acknowledging and addressing sensory issues [e.g., skin health management], incontinence, impaired autonomic nervous system as applicable). In the gym, we adapt exercises per the functional capacity of each athlete in order to train them on their functional horizon. Beyond that, no difference in training and coaching style.

Adam Bleakney, Wheelchair T&F coach for over 13 years, coach of multiple Paralympic medallists from 100 m to marathon. Three-time Paralympian, Athens silver medallist 800 m.

6.4 SWEAT LOSSES AND FLUID REPLACEMENT

It is well known that appropriate fluid replacement is vital to good performance in AB athletes, as outlined in Chapter 5. Within the literature pertaining to athletes with a spinal cord injury, no studies have reported a direct comparison between fluid consumption and no fluid consumption and the effects on performance. The main data available concerning fluid intake has been reported through studies of thermoregulation where ad libitum drinking was allowed during prolonged bouts of exercise in cool and hot conditions (Griggs et al. 2015, 2017a,b; Price and Campbell 1997, 1999, 2003).

Price (2006) noted that from studies of thermoregulation in athletes with SCI, it was clear that those athletes with low-level thoracic spinal cord injuries lost more sweat than those with high-level thoracic spinal cord injuries, who in turn lost more than athletes with quadriplegia. Such responses demonstrated the proportional loss of SNS innervation in relation to the level of SCI and the subsequent ability to sweat in athletes with paraplegia and the loss of sweating capacity in athletes with quadriplegia (Hopman et al. 1993). Fluid losses during continuous arm crank exercise (60% $\dot{V}O_{2peak}$, 60 min) in cool conditions (21°C) for AB athletes and those with paraplegia have been reported as 0.99 and 0.78 L/h, respectively (Price and Campbell, 1997). For the same protocol during wheelchair exercise in warm conditions (31°C), athletes with high-level (T1–T5) and low-level (T6 and below) SCI have shown similar fluid losses, at approximately 0.71 and 0.69 L/h, respectively (Price and Campbell 2003). When compared to upper body–trained AB athletes, sweat loss values were ~1.3 L/h, whereas the athletes with quadriplegia lost 0.31 L/h (Price and Campbell 2003). More recent data (Griggs et al. 2015, 2017a,b) focusing upon intermittent court-based sports in cool conditions for wheelchair rugby players confirms the severe reduction of or loss of sweating capacity, with sweat losses of 0.0–0.34 L/h. It is of interest to note that when exercising in the heat, AB athletes are able to increase their sweat rate, whereas those with paraplegia appear not to be able to, suggesting that maximal sweat rates may have already been attained (Price and Campbell 2006).

From the studies noted above examining continuous exercise in cool conditions (21°C), the AB athletes and those athletes with paraplegia have demonstrated voluntary fluid intakes of approximately 0.6 and 0.4 L/h, thus replacing approximately 52% and 60% of fluid losses (Price and Campbell 1997). From the intermittent sprint-based protocols reflecting on-court sports (i.e., wheelchair rugby and basketball), fluid intake values for athletes with quadriplegia (540 mL) and paraplegia (469 mL) were no different, suggesting similar drinking habits between these two groups (Griggs et al. 2015). However, in a more demanding intermittent sprint protocol (Griggs et al. 2017a,b) with greater increases in deep body temperature, larger ad libitum drinking volumes were noted for the athletes with quadriplegia (819 mL). Such an increase in fluid consumption is likely due to the greater thermal strain the athletes were under rather than (predominantly absent) sweat losses.

Increases in fluid consumption in relation to greater thermal strain as a result of sweating dysfunction have also been seen during exercise in warm conditions. For example, athletes with quadriplegia ingested greater volumes of fluid than their paraplegic counterparts during prolonged continuous exercise in warm conditions (764 and ~430 L/h, respectively; Price and Campbell 2003). Interestingly, this is a similar volume to that observed during the intermittent sprint protocols and may suggest an upper limit of fluid ingestion in these athletes. As with exercise in cool conditions, athletes with paraplegia have demonstrated voluntary fluid intakes similar to those in AB athletes (i.e., 50%–55% of fluid losses) during exercise in the heat.

In conjunction with greater thermal strain increasing voluntary fluid intake in athletes with quadriplegia, more practical factors are also of importance. Such factors have been noted anecdotally by athletes with quadriplegia playing wheelchair rugby and wheelchair tennis. Athletes will either drink a lot of fluid in response to large increases in body temperature, or conversely, they will restrict fluid intake to avoid gains in body mass from drinking (but not losing fluid through sweating), which athletes consider will affect their on-court performance. Drinking large amounts of fluid may have serious negative effects for athletes with quadriplegia or high-level thoracic injuries with respect to inducing autonomic dysreflexia (an acute condition where an exaggerated release of norepinephrine results in a large increase in blood pressure; Price 2010), which can be triggered by a range of factors including a full bladder. Athletes who are prone to such conditions should take medical advice, and the reader is guided to Chapter 12. In addition, athletes should consider measures to reduce core temperature that don't involve fluid intake, as outlined in Chapter 5, since excessive fluid intakes relative to sweat losses are unnecessary.

Another scenario where fluid replacement may be of importance is for sports where protective clothing is worn, such as wheelchair fencing. Although such competitions are usually undertaken in sports halls rather than outside in more extreme environments, the potential increases in body temperature and sweat losses should not be underestimated. Unfortunately, there are no data available at this time to provide guidelines for fluid replacement in these instances, but athletes should become aware of how to measure body mass changes pre- and postexercise and determine their own sweat rate to help guide their fluid replacement needs (see Chapter 5 for further details).

6.5 PRACTICAL ASPECTS

6.5.1 How Should an Athlete with SCI Approach Changing Their Body Composition?

Reducing body fat in athletes with SCI can be harder than for AB athletes. A reduced functional mass in these athletes, especially those with high and/or complete lesions, means a lower total EE and hence a lower EI is required to maintain energy balance. A further reduction in EI to induce a caloric deficit can be difficult for a number of reasons: (a) the volume of food is much less than the athlete's "norm" prior to SCI and potentially to others around them; (b) it can appear impossible to meet macro- and micronutrient recommendations for athletes, but remember these are not SCI specific; and (c) some common medications can affect appetite and mood, which can have knock-on effects on EI.

When developing a weight reduction plan, consider the athlete's daily and training EE and periodise their EI accordingly. To do this, it is often useful to consider what proportion of their body mass is functional and adapt AB guidelines accordingly. Maintenance of protein intake in athletes (at least 1.2–1.6 g/kg/d in those who do not have pressure ulcers) is important to help maintain lean body mass during a period of caloric deficit. At the same time, carbohydrate intake can be periodised to reduce overall EI while ensuring the athlete has sufficient fuel to complete each training session with quality, for example, providing carbohydrates in the pre-exercise meal or during a prolonged session, while reducing their intake on lighter training days. Focus on nutrient-dense foods to help obtain sufficient micronutrients despite a reduced total energy intake. Remember that every athlete is individual and due to a lack of research in this area, you may need to adjust the plan regularly based on easily accessible monitoring tools such as body mass, circumference measurements and skinfolds.

6.5.2 How Can an Athlete with SCI Measure and Maintain Their Hydration Status?

Dehydration affects most people whether they are athletes or not. Large-scale studies have shown that many people are regularly dehydrated because of inadequate fluid intake on a daily basis (Kenney et al. 2015), not just through exercise sweat losses (Emerson et al. 2017), so education regarding fluid replacement is often required. In addition, athletes can often turn up to training sessions in a dehydrated state (Lee et al. 2017). This is likely to be no different in athletes with SCI; however, it may not be as straightforward as for the AB. For example, the level of lesion determines the sweat losses during exercise (Price and Campbell 2003); therefore, athletes with higher lesions theoretically need to replace less fluid than those with lower-level lesions. Sometimes these athletes may only replace 50% of fluid losses during exercise in the heat (Price and Campbell 2003), which is an area that warrants future research. In addition, those athletes who have cervical injuries (i.e., quadriplegic) and do sweat can still have fluid deficit as a result of urine losses, so fluids still need to be replaced. The question is, therefore, how can you determine your fluid requirements and avoid being dehydrated, and how can you monitor your hydration status?

In the scientific literature, markers such as blood osmolality and sodium concentration, urine osmolality and urine-specific gravity are often used to indicate hydration levels (for review, see Lee et al. 2017). However, these are impractical for use by most people. Luckily, we can accurately assume that 1 kg of body mass loss is equal to 1 L of sweat (Lee et al. 2017). Therefore, changes in body mass are indicative of fluid losses (considering fluid intake and other losses such as those in urine). Indeed, a reduction in body mass of 2% is often linked to deceases in performance. Body mass can be monitored over consecutive days to determine a "normal" value and then compared to those when greater sweat losses are likely to have occurred (i.e., harder or longer training sessions, exercise in the heat etc.). For those athletes unable to source accessible weighing scales, other hydration measures can be used. A common alternative measure to body mass is that of urine colour, which is reliable for assessing hydration (Lee et al. 2017). So, whether large sweat losses or no sweating occurs, urine colour can be used to determine hydration status.

In terms of fluid replacement, people are often dehydrated before they become thirsty (Lee et al. 2017) so relying on our own thirst is not always the best approach. Simply increasing daily fluid intake by relatively small amounts (i.e., 250 mL–1 L of water) has positive effects on hydration status and reduces the risk of dehydration (Kenney et al. 2015; Villiger et al. 2018). Some studies have examined both ad libitum drinking and individualised drinking strategies, based on sweat and electrolyte losses,

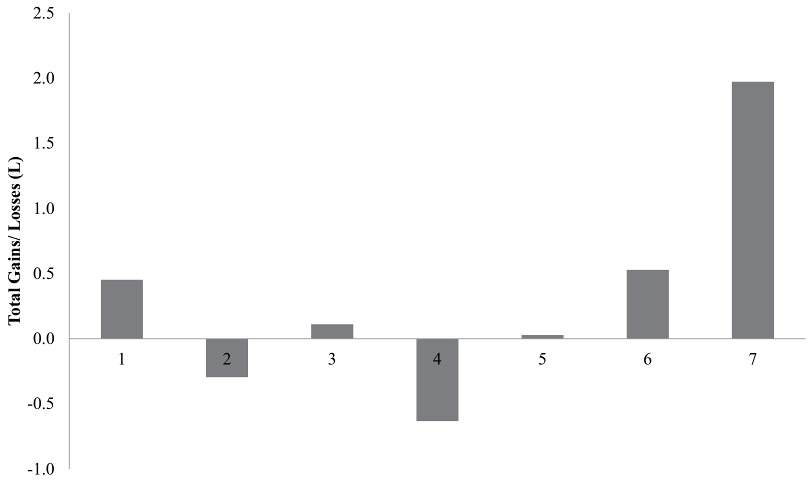


FIGURE 6.6 Fluid balance in wheelchair rugby players following a 60-min scrimmage session. Each number represents an individual athlete.

for improving hydration status during exercise. Most show that either strategy can reduce fluid losses and that beginning exercise in a euhydrated state reduces thermal, physiological and perceptual strain (Emerson et al. 2017). Therefore, increasing hydration throughout the day and practising with fluid replacement regimes in training (and certainly prior to competition) is key. However, in athletes with quadriplegia, thirst and fluid intake can be driven more by core temperature increases and may be disproportionate to sweat losses, resulting in greater fluid intake than is required. This “overhydration” is not recommended, as it may result in increased urinary electrolyte losses and the risk of autonomic dysreflexia and/or high urine outputs. As such, these athletes may require different messaging around hydration than what is typical for most athletes (Figure 6.6).

6.5.3 Practitioner's Note

Dr Sophie Killer

Former Lead Performance Nutritionist, British Athletics

Numerous factors impact performance nutrition considerations when working with athletes with SCI. For example, extra thought is required when planning race day hydration strategies for endurance athletes: the ability for fluid to be carried on or in the chair and the additional weight considerations of this, whether it is possible to prevent fluids getting too hot during racing and ultimately the ability of the athlete to ingest fluids while pushing at high speeds.

For any wheelchair athlete, extra care needs to be taken around gastrointestinal comfort during both training and racing due to their position in the chair, so careful pretraining/race meal planning and preparation is essential. Away from training and competition, other key nutrition considerations include investigating the athlete's ability to absorb nutrients and monitoring nutrient status using a range of biomarkers. Finding appropriate methods to monitor body composition can be challenging but often plays an important role in optimising performance. It is important to note that significant changes in body mass too close to competition can have huge implications on the fit and feel of the race chair, which can be detrimental to performance.

6.6 TAKE-HOME MESSAGES

1. In general, practitioners working with individuals with SCI can employ the same underpinning nutrition principles as for AB yet with subtle but significant alterations. A thorough needs analysis is essential to determine the nature and level of SCI as well as sporting discipline.
2. Gastric emptying can be slowed in persons with SCI compared to AB persons. If concerns around gastric motility exist, a physician should be consulted.
3. Energy expenditure, and thus EI, for athletes with SCI is less than AB athletes, making it more challenging to meet some of the recommended micronutrient intakes. This reduced EI highlights the importance of incorporating nutrient-dense foods.
4. Ingestion of water and/or CHO drinks is likely to improve endurance performance. However, athletes should be cautioned not to drink too much fluid if they are susceptible to autonomic dysreflexia while remembering to include this CHO consumption in daily EI calculations.
5. Vitamin D status should be measured in all athletes with SCI, with appropriate repletion with oral vitamin D supplements where necessary.
6. Sweat losses are generally proportional to the level of SCI, with those athletes with quadriplegia generally having an absent or much reduced ability to sweat.
7. Sweat rates must be determined for each individual athlete under different environmental conditions to optimise the hydration and/or cooling strategy.

COMMENTARY BOX 6.3: LATEX ALLERGIES

SPECIAL COMMENTARY: Latex Allergies

It is relatively common for athletes with spina bifida and other congenital physical impairments who have undergone numerous surgeries to develop a latex allergy due to frequency of exposure over their lifetime. While it might seem obvious that care should be taken in regards to choice of gloves when used by practitioners (i.e., choosing latex-free gloves), latex is found in a number of products, and those with latex allergies can also be allergic to certain foods. The most common reaction is a skin irritation, hives or rash; however, reactions can be more extreme, including asthma symptoms and anaphylaxis. It is important to check with athletes regarding their known sensitivity to latex and whether foods can cause issues.

Other products containing latex:	*Foods which may result in an itchy mouth or swelling of the throat:*
Bandaids/sticking plasters	Bananas
Rubber grips (i.e., in the kitchen)	Kiwi fruit
Rubber bands	Avocado
Balloons	Plums
Condoms & diaphragms use for contraception	Strawberries
Catheters	Tomato
Elastic waistbands in clothes	Passionfruit
Rubber-soled shoes	Chestnuts
Rubber bath mats	Take-away food where the food handler was wearing latex gloves

REFERENCES

Abel, T., Platen, P., Rojas Vega, S., Schneider, S. and Strüder, H.K. 2008. Energy expenditure in ball games for wheelchair users. *Spinal Cord* 46:785–790.

Ainsworth, B.E., Haskell, W.L., Whitt, M.C. et al. 2000. Compendium of physical activities: An update of activity codes and MET intensities. *Medicine and Science in Sports and Exercise* 32(Suppl. 9):S498–S504.

Alexander, L.R., Spungen, A.M., Liu, M.H., Losanda, M. and Bauman, W.A. 1995. Resting metabolic rate in subjects with paraplegia: The effect of pressure sores. *Archives of Physical Medicine and Rehabilitation* 76:819–822.

American Spinal Injury Association. 2016. International Standards for Neurological Classification of Spinal Cord Injury, Atlanta, GA. Accessed April 2018. http://asia-spinalinjury.org/wp-content/uploads/2016/02/International_Stds_Diagram_Worksheet.pdf

Astorino, T.A. and Harness, E.T. 2009. Substrate metabolism during exercise in spinal cord injured. *European Journal of Applied Physiology* 106:187–193.

Bauman, W.A., Emmons, R.R., Cirnigliaro, C.M., Kirshblum, S.C. and Spungen, A.M. 2011. An effective oral vitamin D replacement therapy in persons with spinal cord injury. *Journal of Spinal Cord Medicine* 34:455–460.

Bauman, W.A., Spungen, A.M., Wang, J., Pierson, R.N., Jr. and Schwartz, E. 1999. Continuous loss of bone during chronic immobilization: A monozygotic twin study. *Osteoporosis International* 10:123–127.

Beerepoot, M.A., ter, R.G., Nys, S. et al. 2012. Lactobacilli vs antibiotics to prevent urinary tract infections: A randomized, double-blind, noninferiority trial in postmenopausal women. *Archives of Internal Medicine* 172:704–712.

Bernardi, M., Canale, I., Felici, F. and Marchettoni, P. 1988. Field evaluation of the energy cost of different wheelchair sports. *International Journal of Sports Cardiology* 5:58–61.

Buchholz, A.C. and Pencharz, P.B. 2004. Energy expenditure in chronic spinal cord injury. *Current Opinion in Clinical Nutrition and Metabolic Care* 7:635–639.

Burke, E.J., Auchinachie, J.A., Hayden, R. and Loftin, J.M. 1985. Energy cost of wheelchair basketball. *Physician and Sports Medicine* 13:99–102.

Burke, L. 2015. Preparation for competition. In: *Clinical Sports Nutrition* (5th edn), eds. Burke, L. and Deakin, V. pp. 346–376. Sydney: McGraw-Hill.

Burleigh, A.E., Benck, S.M., McAchran, S.E., Reed, R.D., Kruger, C.G. and Hopkins, W.J. 2013. Consumption of sweetened, dried cranberries may reduce urinary tract infection incidence in susceptible women – A modified observational study. *Nutrition Journal* 12:139.

Cameron, K.J., Nyulasi, I.B., Collier, G.R. and Brown, D.J. 1996. Assessment of the effect of increased dietary fibre intake on bowel function in patients with spinal cord injury. *Spinal Cord* 34:277–283.

Chun, S.M., Kim, H.R. and Shin, H.I. 2017. Estimating the basal metabolic rate from fat free mass in individuals with motor complete spinal cord injury. *Spinal Cord* 55:844–847.

Chung, E.A. and Emmanuel, A.V. 2006. Gastrointestinal symptoms related to autonomic dysfunction following spinal cord injury. *Progress in Brain Research* 152:317–333.

Collins, E.G., Gater, D., Kiratli, J., Butler, J., Hanson, K. and Langbein, W.E. 2010. Energy cost of physical activities in persons with spinal cord injury. *Medicine and Science in Sports and Exercise* 42:691–700.

Compton, S., Trease, L., Cunningham, C. and Hughes, D. 2015. Australian Institute of Sport and the Australian Paralympic Committee position statement: Urinary tract infection in spinal cord injured athletes. *British Journal of Sports Medicine* 49:1236–1240.

Croft, L., Dybrus, S., Lenton, J. and Goosey-Tolfrey, V. 2010. A comparison of the physiological demands of wheelchair basketball and wheelchair tennis. *International Journal of Sports Physiology and Performance* 5:301–315.

Dauty, M., PerrouinVerbe, B., Maugars, Y., Dubois, C. and Mathe, J.F. 2000. Supralesional and sublesional bone mineral density in spinal cord injured patients. *Bone* 27:305–309.

de Bruin, E.D., Dietz, V., Dambacher, M.A. and Stussi, E. 2000. Longitudinal changes in bone in men with spinal cord injury. *Clinical Rehabilitation* 14:145–152.

Edwards, T., Barfield, J.P., Neimiro, G.M. et al. 2018. Physiological responses during a 25-km time trial in elite wheelchair racing athletes. *Spinal Cord Series and Cases* 4:77.

Emerson, D.M., Torres-McGehee, T.M., Emerson, C.C. and LaSalle, T.L. 2017. Individual fluid plans versus ad libitum on hydration status in minor professional ice hockey players. *Journal of the International Society of Sports Nutrition* 14:25.

Eser, P., Frotzler, A., Zehnder, Y. and Denoth, J. 2005. Fracture threshold in the femur and tibia of people with spinal cord injury as determined by peripheral quantitative computed tomography. *Archives in Physical Medicine and Rehabilitation* 86:498–504.

Flueck, J.L., Hartmann, K. and Perret, C. 2016. Vitamin D deficiency in Swiss elite wheelchair athletes. *Spinal Cord* 54:991–995.

Flueck, J.L. and Perret, C. 2017. Vitamin D deficiency in individuals with a spinal cord injury: A literature review. *Spinal Cord* 55:428–434.

Gerrish, H.R., Broad, E., Lacroix, M., Ogan, D., Pritchett, R.C. and Pritchett, K. 2017. Nutrient intake of elite Canadian and American athletes with spinal cord injury. *International Journal of Exercise Science* 10:1018–1028.

Glaser, R.M. 1985. Exercise and locomotion for the spinal cord injured. *Exercise and Sport Science Reviews* 13:263–303.

Goktepe, A.S., Yilmaz, B., Alaca, R., Yazicioglu, K., Mohur, H. and Gunduz, S. 2004. Bone density loss after spinal cord injury: Elite paraplegic basketball players vs. paraplegic sedentary persons. *American Journal of Physical Medicine and Rehabilitation* 83:279–283.

Gollnick, P. D., Armstrong, R. B., Saubert, C. W., Piehl, K. and Saltin, B. 1972. Enzyme activity and fiber composition in skeletal muscle of untrained and trained men. *Journal of Applied Physiology* 33:312–319.

Goosey-Tolfrey, V.L. and Crosland, J. 2010. Nutritional practices of competitive British wheelchair games players. *Adapted Physical Activity Quarterly* 27:47–59.

Goosey-Tolfrey, V.L., Keil, M., Brooke-Wavell, K. and de Groot, S. 2016. A comparison of methods for the estimation of body composition in highly trained wheelchair games players. *International Journal of Sports Medicine* 37:799–806.

Goosey-Tolfrey, V.L. and Price, M.J. 2010. Physiology of wheelchair athletes. In *Wheelchair Sport*, ed. Goosey-Tolfrey, V. pp. 47–62. Champaign, IL: Human Kinetics.

Goosey-Tolfrey, V.L. and Sutton, L. 2012. Disability, chronic disease and body composition. In *Body Composition in Sport, Exercise and Health*, eds. Stewart, A. and Sutton, L. pp. 166–186. London: Routledge.

Graham-Paulson, T.S., Paulson, T.A.W., Perret, C., Tolfrey, K., Cordery, P. and Goosey-Tolfrey, V.L. 2017. Spinal cord injury level influences acute plasma caffeine responses. *Medicine and Science in Sports and Exercise* 49:363–370.

Griggs, K.E., Havenith, G., Paulson, T.A.W., Price, M.J. and Goosey-Tolfrey, V.L. 2017a. Effects of cooling before and during simulated match play on thermoregulatory responses of athletes with tetraplegia. *Journal of Science and Medicine in Sport* 20:819–824.

Griggs, K.E., Havenith, G., Price, M.J., Mason, B.S. and Goosey-Tolfrey, V.L. 2017b. Thermoregulatory responses during competitive wheelchair rugby match play. *International Journal of Sports Medicine* 38:177–183.

Griggs, K.E., Leicht, C.A., Price, M.J. and Goosey-Tolfrey, V.L. 2015. Thermoregulation during intermittent exercise in athletes with a spinal-cord injury. *International Journal of Sports Physiology and Performance* 10:469–475.

Groah, S.L., Nash, M.S., Ljungberg, I.H. et al. 2009. Nutrient intake and body habitus after spinal cord injury: An analysis by sex and level of injury. *Journal of Spinal Cord Medicine* 32:25–33.

Hamilton, B. 2011. Vitamin D and athletic performance: The potential role of muscle. *Asian Journal of Sports Medicine* 2:211–219.

Heaney, R.P. 1999. Lessons for nutritional science from vitamin D. *American Journal of Clinical Nutrition* 69:825–826.

Helge, J.W. 2010. Arm and leg substrate utilisation and muscle adaptation after prolonged low-intensity training. *Acta Physiologica* 199:519–528.

Hess, M.J., Hess, P.E., Sullivan, M.R., Nee, M. and Yalla, S.V. 2008. Evaluation of cranberry tablets for the prevention of urinary tract infections in spinal cord injured patients with neurogenic bladder. *Spinal Cord* 46:622–626.

Hopman, M.T.E., Oeseburg, B. and Binkhorst, R.A. 1993. Circulatory responses in persons with paraplegia to prolonged arm exercise and thermal stress. *Medicine and Science in Sports and Exercise* 25:577–583.

Iglesias, X., Rodríguez, A., Tarragó, R. et al. 2018. Physiological demands of standing and wheelchair fencing in able-bodied fencers. *The Journal of Sports Medicine and Physical Fitness*. DOI: 10.23736/S0022-4707.18.08413-X.

International Paralympic Committee (IPC) 2018. Accessed April, 2018 https://www.paralympic.org/athletics/classification

Jacobs, P.L. and Nash, M.S. 2004. Exercise recommendations for individuals with spinal cord injury. *Sports Medicine* 34:727–751.

Janssen, T.W.J. and Hopman, M.T.E. 2005. Spinal cord injury. In *Exercise Testing and Exercise Prescription for Special Cases* (3rd edn), ed. Skinner J.S. pp. 203–219. Baltimore: Lippincott Williams and Wilkins.

Jung, W. and Yamasaki, M. 2009. Effect of pre-exercise carbohydrate ingestion on substrate consumption in persons with spinal cord injury. *Spinal Cord* 47:464–469.

Kao, C.H., ChangLai, S.P., Chieng, P.U. and Yen, T.C. 1998. Gastric emptying in male neurologic trauma. *Journal of Nuclear Medicine* 39:1798–1801.

Kao, C.H., Ho, Y.J., Changlai, S.P. and Ding, H.J. 1999. Gastric emptying in spinal cord injury patients. *Digestive Diseases and Sciences* 44:1512–1515.

Keil, M., Totosy de Zepetnek, J.O., Brooke-Wavell, K. and Goosey-Tolfrey, V.L. 2016. Measurement precision of body composition variables in elite wheelchair athletes, using dual-energy x-ray absorptiometry. *European Journal of Sport Sciences* 13:1–7.

Kenney, E.L., Long, M.D., Cradock, A.L. and Gortmaker, S.L. 2015. Prevalence of inadequate hydration among US children and disparities by gender and race/ethnicity: National Health and Nutrition Examination Survey, 2009–2012. *American Journal of Public Health* 105:e113–e118.

Killerich, K., Birk, J.B., Damsgaard, R., Wojaszewski, J.F.P. and Pilegaard, H. 2008. Regulation of PDH in human arm and leg muscles at rest and during intense exercise. *American Journal of Physiology, Endocrinology and Metabolism* 294:E36–E42.

Knechtle, B., Müller, G. and Knecht, H. 2004. Optimal exercise intensities for fat metabolism in handbike cycling and cycling. *Spinal Cord* 42:564–572.

Kranjcec, B., Papes, D. and Altarac, S. 2014. D-mannose powder for prophylaxis of recurrent urinary tract infections in women: A randomized clinical trial. *World Journal of Urology* 32:79–84.

Krempien, J.L. and Barr, S.I. 2011. Risk of nutrient inadequacies in elite Canadian athletes with spinal cord injury. *International Journal of Sport Nutrition and Exercise Metabolism* 21:417–425.

Krempien, J.L. and Barr, S.I. 2012. Eating attitudes and behaviours in elite Canadian athletes with a spinal cord injury. *Eating Behavior* 13:36–41.

Kressler, J., Burns, P.A., Betancourt, L. and Nash, M.S. 2014. Circuit training and protein supplementation in persons with chronic tetraplegia. *Medicine and Science in Sports and Exercise* 46:1277–1284.

Lee, E.A., Fragala, M.S., Kavouras, A.S., Queen, R.M., Pryor, J.L. and Casa, D.J. 2017. Biomarkers in sports and exercise: Tracking, health, performance, and recovery in athletes. *Journal of Strength and Conditioning Research* 31:2920–2937.

Lee, S., Posthauer, M., Dorner, B., Redovian, V. and Maloney, M. 2006. Pressure ulcer healing with a concentrated, fortified, collagen protein hydrolysate supplement: A randomized controlled trial. *Advances in Skin Wound Care* 19:92–96.

Leicht, C., Bishop, N.C. and Goosey-Tolfrey, V.L. 2012. Submaximal exercise responses in tetraplegic, paraplegic and non spinal cord injured elite wheelchair athletes. *Scandinavian Journal of Medicine and Science in Sport* 22:729–736.

Leiper, J.B., Broad, N.P. and Maughan, R.J. 2001a. Effect of intermittent high-intensity exercise on gastric emptying in man. *Medicine and Science in Sports and Exercise* 33:1270–1278.

Leiper, J.B., Nicholas, C.W., Ali, A., Williams, C. and Maughan, R.J. 2005. The effect of intermittent high-intensity running on gastric emptying of fluids in man. *Medicine and Science in Sports and Exercise* 37:240–247.

Leiper, J.B., Prentice, A.S., Wrightson, C. and Maughan, R.J. 2001b. Gastric emptying of a carbohydrate-electrolyte drink during a soccer match. *Medicine and Science in Sports and Exercise* 33:1932–1938.

Levine, A.M., Nash, M.S., Green, B.A., Shea, J.D. and Aronica, M.J. 1992. An examination of dietary intakes and nutritional status of chronic healthy spinal cord injured individuals. *Paraplegia* 30:880–889.

Lin, V.W., Kim, K.H., Hsiao, I. and Brown, W. 2002. Functional magnetic stimulation facilitates gastric emptying. *Archives of Physical Medicine and Rehabilitation* 83:806–810.

Liusuwan, A., Widman, L., Abresch, R.T. and McDonald, C.M. 2004. Altered body composition affects resting energy expenditure and interpretation of body mass index in children with spinal cord injury. *The Journal of Spinal Cord Medicine* 27(Suppl. 1):S24–S28.

Lu, C.L., Montgomery, P., Zou, X., Orr, W.C. and Chen, J.D. 1998. Gastric myoelectrical activity in patients with cervical spinal cord injury. *American Journal of Gastroenterology* 93:2391–2396.

McArdle, W.D., Katch, F.I. and Katch, V.L. 2000. *Exercise Physiology; Energy, Nutrition and Human Performance* (2nd edn). Philadelphia: Lea and Febiger.

Mestre, H., Alkon, T., Salazar, S. and Ibarra, A. 2011. Spinal cord injury sequelae alter drug pharmacokinetics: An overview. *International Spinal Cord Society* 49:955–960.

Mizuno, M., Juel, C., Bro-Rasmussen, T., Mygind, E., Schibye, B., Rasmussen, B. and Saltin, B. 1990. Limb skeletal muscle adaptation in athletes after training at altitude. *Journal of Applied Physiology* 68:496–502.

Mollinger, L.A., Spurr, G.B., Ghatit, E.I., Barboriak, J.J., Rooney, C.B. and Davidoff, D.D. 1985. Daily energy expenditure and basal metabolic rates in patients with spinal cord injury. *Archives of Physical Medicine and Rehabilitation* 66:420–426.

Monroe, M.B., Tataranni, P.A., Pratley, R., Manore, M.M., Skinner, J.S. and Ravussin, E. 1998. Lower daily energy expenditure as measured by a respiratory chamber in subjects with spinal cord injury compared with control subjects. *The American Journal of Clinical Nutrition* 68:1223–1227.

Mygind, E. 1995. Fibre characteristics and enzyme levels of arm and leg muscles in elite cross-country skiers. *Scandinavian Journal of Medicine and Science in Sports* 5:76–80.

Navarrete-Opazo, A., Cuitino, P. and Salas, I. 2017. Effectiveness of dietary supplements in spinal cord injury subjects. *Disability Health* 10:183–197.

Nemunaitis, G.A., Mejia, M., Nagy, J.A., Johnson, T., Chae, J. and Roach, M.J. 2010. A descriptive study on vitamin D levels in individuals with spinal cord injury in an acute inpatient rehabilitation setting. *Physical Medicine and Rehabilitation* 2:202–208.

Nevin, A., Mayr, H., Atresh, S. et al. 2016. Feasibility and acceptability of implementing indirect calorimetry into routine clinical care of patients with spinal cord injury. *Topics in Spinal Cord Injury Rehabilitation* 22:269–276.

Nightingale, T.E. and Gorgey, A.S. 2018. Predicting basal metabolic rate in men with motor complete spinal cord injury. *Medicine and Science in Sports and Exercise* 50:1305–1312.

Oleson, C.V., Patel, P.H. and Wuermser, L.A. 2010. Influence of season, ethnicity, and chronicity on vitamin D deficiency in traumatic spinal cord injury. *Journal of Spinal Cord Medicine* 33:202–213.

Patt, P.L., Agena, S.M., Vogel, L.C., Foley, F. and Anderson, C.J. 2007. Estimation of resting energy expenditure in children with spinal cord injuries. *The Journal of Spinal Cord Medicine* 30:S83–S87.

Patterson, S.D. and Gray, S.C. 2007. Carbohydrate-gel supplementation and endurance performance during intermittent high-intensity shuttle running. *International Journal of Sports Nutrition and Exercise Metabolism* 17:445–455.

Paulson, T., Leicht, C., Bishop, N. and Goosey-Tolfrey, V.L. 2013. Perceived exertion as a tool to self-regulate exercise in individuals with tetraplegia. *European Journal of Applied Physiology* 113:201–209.

Pelly, F.E., Broad, E.M., Stuart, N. and Holmes, M.A. 2018. Resting energy expenditure in male athletes with a spinal cord injury. *The Journal of Spinal Cord Medicine* 41:208–215.

Potvin, A., Nadon, R., Royer, D. and Farrar, D. 1996. The diet of the disabled athlete. *Science and Sports* 11:152–156.

Price, M.J. 2006. Thermoregulation during exercise in individuals with spinal cord injuries. *Sports Medicine* 20:457–463.

Price, M.J. 2010. Energy expenditure and metabolism during exercise in persons with a spinal cord injury. *Sports Medicine* 40:681–696.

Price, M.J. and Campbell, I.G. 1997. Thermoregulatory responses of able-bodied and paraplegic athletes to prolonged upper body exercise. *European Journal of Applied Physiology* 76:552–560.

Price, M.J. and Campbell, I.G. 1999. Thermoregulatory responses of able-bodied, paraplegic and a tetraplegic athlete at rest, during prolonged upper body exercise and during passive recovery. *Spinal Cord* 37:772–779.

Price, M.J. and Campbell, I.G. 2003. Effects of spinal cord lesion level upon thermoregulation during exercise in the heat. *Medicine and Science in Sports and Exercise* 35:1100–1107.

Price, M.J. and Campbell, I.G. 2006. Thermoregulatory responses of athletes with a spinal cord injury to prolonged wheelchair exercise in cool and warm conditions. In *Focus on Exercise and Health Research*, Nova Science Publications. pp. 203–220.

Pritchett, K., Pritchett, R.C., Ogan, D., Bishop, P. and Broad, E. 2016. 25(OH)D status of elite athlete with spinal cord injury relative to lifestyle factors. *Nutrients* 8:374.

Pritchett, K., Pritchett, R.C., Stark, L., Broad, E. and LaCroix, M. 2018. Effect of vitamin D supplementation on 25(OH)D status in elite athletes with spinal cord injury. *International Journal of Sport Nutrition and Exercise Metabolism* 14:1–23.

Reddy, M., Gill, S.S., Kalkar, S.R., Wu, W., Anderson, P.J. and Rochon, P.A. 2008. Treatment of pressure ulcers: A systematic review. *Journal of the American Medical Association* 300:2647–2662.

Ribeiro, S.M., Da Silva, R.C., De Castro, I.A. and Tirapegui, J. 2005. Assessment of nutritional status of active handicapped individuals. *Nutrition Research* 25:239–249.

Roy, J.L., Menear, K.S., Schmid, M.M., Hunter, G.R. and L.A. Malone. 2006. Physiological responses of skilled players during a competitive wheelchair tennis match. *Journal of Strength and Conditioning Research* 20:665–671.

Schantz, P., Sjöberg, B., Widesbeck, A. and Ekblom, B. 1997. Skeletal muscle of trained and untrained paraplegics and tetraplegics. *Acta Physiologica Scandinavica* 161:31–39.

van der Scheer, J.W., Hutchinson, M., Paulson, T.P., Martin Ginis, K.A. and Goosey-Tolfrey V.L. 2018. Reliability and validity of subjective measures of aerobic intensity in adults with spinal cord injury: A systematic review. *PM&R* 10:194–207.

Schmid, A., Huonker, M., Barturen, J.M. et al. 1998. Catecholamines, heart rate, and oxygen uptake during exercise in persons with spinal cord injury. *Journal of Applied Physiology* 85:635–641.

Spendiff, O. and Campbell, I.G. 2002. The effect of glucose ingestion on endurance upper-body exercise and performance. *International Journal of Sports Medicine* 23:142–147.

Spendiff, O. and Campbell, I.G. 2003. Influence of glucose ingestion prior to prolonged exercise on selected responses of wheelchair athletes. *Adapted Physical Activity Quarterly* 20:80–90.

Spendiff, O. and Campbell, I.G. 2005. Influence of pre-exercise glucose ingestion of two concentrations on paraplegic athletes. *Journal of Sports Science* 23:21–30.

Spungen, A.M., Adkins, R.H., Stewart, C.A. et al. 2003. Factors influencing body composition in persons with spinal cord injury: A cross-sectional study. *Journal of Applied Physiology* 95:2398–2407.

Spungen, A.M., Wang, J., Pierson, R.N. and Bauman, W.A. 2000. Soft tissue body composition differences in monozygotic twins discordant for spinal cord injury. *Journal of Applied Physiology* 88:1310–1315.

Stallknecht, B., Lorentsen, J., Enevoldsen, L.H. et al. 2001. Role of the sympathoadrenergic system in adipose tissue metabolism during exercise in humans. *Journal of Physiology* 536:283–294.

Steinberg, L.L., Lauro, F.A., Sposito, M.M. et al. 2000. Catecholamine response to exercise in individuals with different levels of paraplegia. *Brazilian Journal of Medical and Biological Research* 33:913–918.

Sugiura, K. and Kobayashi, K. 1998. Effect of carbohydrate ingestion on sprint performance following continuous and intermittent exercise. *Medicine and Science in Sports and Exercise* 30:1624–1630.

Sutton, L., Wallace, J., Goosey-Tolfrey, V.L., Scott, M. and Reilly, T. 2009. Body composition of female wheelchair athletes. *International Journal of Sports Medicine* 30:259–265.

Tomey, K.M., Chen, D.M., Wang, X. and Braunschweig, C.L. 2005. Dietary intake and nutritional status of urban community-dwelling mean with paraplegia. *Archives in Physical Medicine and Rehabilitation* 86:664–671.

Tweedy, S. and Diaper, N. 2010. Introduction to wheelchair sport. In *Wheelchair Sport*, ed. Goosey-Tolfrey, V. pp. 3–28. Champaign, IL: Human Kinetics.

Villiger, M., Stoop, R., Vetsch, T. et al. 2018. Evaluation and review of body fluids saliva, sweat and tear compared to biochemical hydration assessment markers within blood and urine. *European Journal of Clinical Nutrition* 72:69–76.

Walters, J.L., Buchholz, A.C. and Martin Ginis, K.A. 2009. Evidence of dietary inadequacy in adults with chronic spinal cord injury. *Spinal Cord* 47:318–322.

Williams, R.E., 3rd, Bauman, W.A., Spungen, A.M. et al. 2012. SmartPill technology provides safe and effective assessment of gastrointestinal function in persons with spinal cord injury. *Spinal Cord* 50:81–84.

Wilmet, E., Ismail, A.A., Heilporn, A., Welreads, D. and Bergmann, P. 1995. Longitudinal study of bone mineral content and soft tissue composition after spinal cord section. *Paraplegia* 33:674–677.

Zhang, R.L., Chayes, Z., Korsten, M.A. and Bauman, W.A. 1994. Gastric emptying rates to liquid or solid meals appear to be unaffected by spinal cord injury. *American Journal of Gastroenterology* 89:1856–1858.

7 Nutrition for Athletes with Cerebral Palsy and Acquired Brain Injuries

Michelle Minehan

CONTENTS

7.1 INTRODUCTION

Cerebral palsy (CP) is a neurological condition that causes physical impairment to movement and posture (CPARF 2018). It is typically caused by damage to the developing brain in utero or brain injury at birth and is considered the most common form of disability in children, with a global incidence of 1 in 500 births (CPARF 2018). The condition is formally defined by the International Executive Committee for the Definition of Cerebral Palsy in Box 7.1.

BOX 7.1 DEFINITION OF CEREBRAL PALSY

Cerebral palsy is a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to nonprogressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication and behaviour; by epilepsy and by secondary musculoskeletal problems.

International Executive Committee for the Definition of Cerebral Palsy, 2005

The brain injury that causes CP is permanent but nonprogressive (Hanna et al. 2009). However, the neural and musculoskeletal symptoms that result from the brain injury can change over time (Verschuren et al. 2018).

The *primary conditions* of CP are directly caused by the brain injury and include impaired motor control (fine and gross), muscle tone, posture and balance (CPARF 2018). However, people experience CP in very different ways. Some athletes with CP have mild muscle stiffness in one arm or leg on one side of the body, whereas other individuals with CP have severe impairments to all four limbs and require a wheelchair to mobilise (Colver et al. 2014).

In addition to primary conditions, people with CP may or may not be affected by a range of related conditions. *Secondary conditions* include difficulties with swallowing, breathing, bladder control, bowel control and communication (CPARF 2018). *Associative conditions* include intellectual impairment, epilepsy, hearing impairment and vision impairment (CPARF 2018). *Co-mitigating factors* include autism, attention deficit disorder and asthma (Colver et al. 2014; CPARF 2018). Pain caused by factors such spasms, contractures, postural problems, gastric reflux and gastrostomy tubes is a commonly reported symptom in children and adults with more severe CP (Opheim et al. 2009; Van der Slot et al. 2012). Children and adults with CP are reportedly more likely to experience psychological difficulties and depressive symptoms than the general population (Opheim et al. 2009; Parkes et al. 2008; Van der Slot et al. 2012). This may be due to disadvantages in social life and employment (Colver et al. 2014) but also possibly due to disrupted neural pathways that regulate emotions and behaviour (Parkes et al. 2008).

The majority of research regarding CP is based on young children. To date, only a handful of studies have been conducted on elite athletes with CP. Bearing in mind that athletes with CP are a heterogeneous population, this chapter aims to review the physiological impacts of CP and consider how nutrition can best support performance in athletes with CP.

Acquired brain injuries (ABIs) are injuries which occur after birth and are not related to congenital or degenerative diseases. In para sport, these injuries are permanent and stable, and result in motor control, muscle tone or balance impairments. They can be caused by a traumatic brain injury (sudden physical damage to the brain), stroke, bleeding in the brain, brain tumours or infections or a lack of oxygen to the brain. As with CP, the manifestation of the brain injury will vary depending on the location and severity of the brain injury and may be associated with neurological as well as physical dysfunction. For the purposes of this chapter, since the physical and neurological consequences of ABI and the classification of athletes with ABI are the same as for CP, the term CP will be used to encompass both conditions.

7.2 CLASSIFICATION OF CEREBRAL PALSY

CP can be described and classified in different ways – according to clinical symptoms, anatomical site of the brain injury, topographical distribution or degree of muscle tone. Figure 7.1 outlines classification systems, and key terms are defined in Table 7.1. For sports nutrition professionals working with athletes with CP for the first time, these different systems and associated terminology can be daunting. It is essential to recognise that each athlete with CP will be affected differently. Asking "How does CP affect you?" and taking the time to explore the individual nuances of CP is recommended.

7.2.1 Classification of Cerebral Palsy in Sport

Initially, CP was one of six medically based classes of disabilities eligible to compete in Paralympic sport (Webborn and Van de Vliet 2012). The current International Paralympic Committee classification code identifies 10 impairments for Paralympic Sports – hypertonia, athetosis, ataxia, impaired muscle power, loss of muscle strength, impaired passive range of motion, loss of limb, limb deficiency, low vision and intellectual impairment (International Paralympic Committee (IPC) 2015). Athletes with CP can be affected by a number of these impairments to different degrees.

Athletes with CP participate in a variety of winter and summer sports, with each sporting organisation outlining the functional classes available for athletes. For example, athletics has T/F 31–38 classes for athletes with CP symptoms (IPC 2015). The "T" refers to "track," "F" refers to "field" and the number indicates the type and severity of the impairment (Australian Paralympic Committee [APC] 2018). Most Paralympic sports cater to athletes with mild to moderate CP, and many elite Para athletes with CP have similar physiology to able-bodied athletes (Runciman et al. 2015). Other athletes with CP have mild to moderate impairments in strength and aerobic capacity. A few sports such as boccia provide an opportunity for athletes with severe CP to compete.

Some example profiles of athletes with CP are provided in Figure 7.2.

Classification of CP

Severity	Topography	Symptoms	Muscle Tone	Site of Brain Injury	Gross Motor Functional Classification Scale
Mild Move without assistance no limit to daily activities **Moderate** May need medication, mobility or daily activity aids **Severe** Wheelchair to mobilise, significant assistance with daily living tasks	Left/Right Hemiplegia Diplegia Quadriplegia	**Spastic CP** Increased muscle tone Muscles continually contract Rigid, stiff, jerky movements **Non-spastic CP** Decreased or fluctuating muscle tone Ataxic or Dyskinetic **Mixed**	**Hypertonia** Increased muscle tone Stiff limbs **Hypotonia** Decreased muscle tone Floppy limbs **Isotonia**	**Pyramidal** Damage to the pyramidal tract **Extra-pyramidal** Damage outside the pyramidal tract **Cerebellum** Damage to the Cerebellum	**Level 1** – community ambulation without support **Level 2** – household ambulation **Level 3** – wheelchair dependent **Level 4** – wheelchair bound **Level 5** – no independent motor function

FIGURE 7.1 Classification of cerebral palsy. (Compiled from Akhter, N. et al. 2017. *The Journal of the Pakistan Medical Association* 67:200–203; CPARF (Cerebral Palsy Alliance Research Foundation). 2018. About Cerebral Palsy. https://research.cerebralpalsy.org.au (Last accessed August 2018); Colver, A. et al. 2014. *Lancet* 383:1240–1249.

TABLE 7.1
Common Terms Used to Describe Symptoms of Cerebral Palsy

Ataxia	Lack of control of movement, including walking, eye movement, fine motor skills
Athetosis	Involuntary muscle contraction – movement may be slow, writhing and repetitive or rhythmic
Chorea	Irregular jerky, shaky movements – not repetitive or rhythmic
Diplegia/Diparesis	Symmetrical paralysis/weakness that affects either the arms or the legs
Dystonia	Involuntary muscle contractions – movement may be twisting, repetitive and patterned
Hemiplegia/Hemiparesis	Paralysis/weakness of the arm and leg on one side of the body
Spasticity	Continual contraction of muscles, causing stiff/tight/rigid muscles

Source: Adapted from Colver, A. et al. 2014. *Lancet* 383:1240–1249; CPARF (Cerebral Palsy Alliance Research Foundation). 2018. About Cerebral Palsy. https://research.cerebralpalsy.org.au (Last accessed August 2018); Larner, A.J. 2016. *A Dictionary of Neurological Signs* (4th edn), London: Springer.

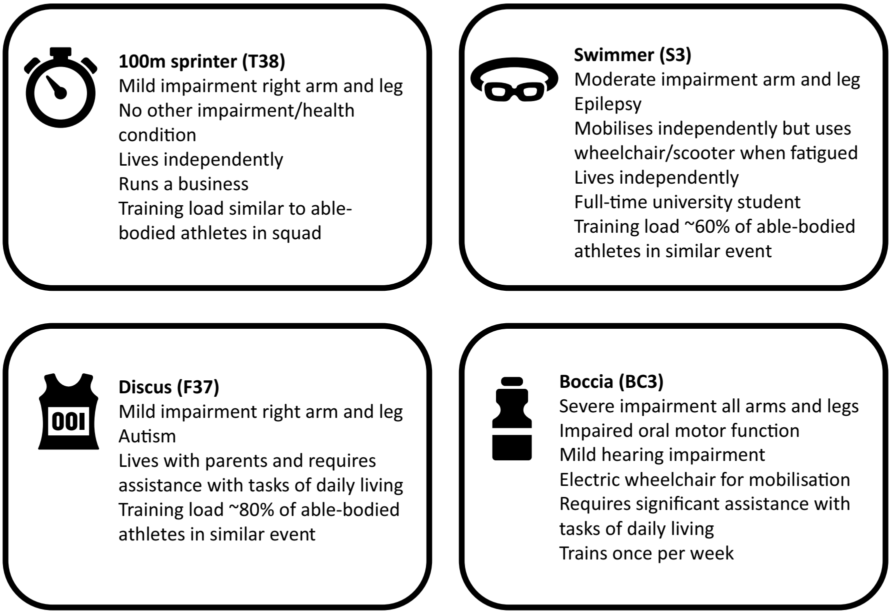


FIGURE 7.2 Example profiles of athletes with cerebral palsy. (Images: istock 2018.)

7.3 BODY COMPOSITION

7.3.1 Growth

Children and adolescents with moderate to severe CP tend to be growth impaired compared to their peers (Andrew and Sullivan 2010; Bell et al. 2010). For example, a retrospective study of patient records of over 24,000 children and adolescents aged 2–20 years reported trends for lower weight and height for age compared to nonaffected peers (Bell et al. 2010). The largest differences in height and weight were seen in those with the most severe impairment (Bell et al. 2010).

Growth of children and adolescents with CP seems to be influenced by a combination of nutrition, neurological and endocrinological influences (Andrew and Sullivan 2010). Nutritional intake can be limited if feeding difficulties such as impaired swallowing or gastrointestinal symptoms such as gastroesophageal reflux disease and constipation are present (Andrew and Sullivan 2010; Bell et al. 2010; Scarpato et al. 2017). Direct damage to neurological pathways caused by the original brain injury may impact growth by interfering with connections between the hypothalamus and body tissues (Andrew and Sullivan 2010; Bell et al. 2010; Stevenson et al. 1994). Endocrine factors such as growth hormone deficiency may also limit growth in children and adolescents with CP (Coniglio et al. 1996; Shim et al. 2004).

7.3.2 Muscle

Unsurprisingly, in many individuals with CP, the muscles in the impaired limb are smaller than the muscles in the unimpaired limb (Barrett and Lichtwark 2010). However, there is also evidence to suggest that the composition of muscle in people with CP may be different from that of nonaffected peers (Peterson et al. 2015; Verschuren et al. 2018). For example, greater connective tissue fraction and more intermuscular and intramuscular fat have been observed in muscle affected by CP (Verschuren et al. 2018). It has been postulated that people with CP may undergo "accelerated ageing," with earlier loss of muscle strength than nonaffected adults (Gillett et al. 2018; Ross et al. 2016).

In the past, it was common practise for children with CP to avoid strength training, as it was thought to increase spasticity and reduce range of motion (Scholtes et al. 2012). However, it is now accepted that strength training improves muscle strength in children and adults with CP with no adverse effects (Beckman et al. 2017; Gillett et al. 2018; Ross et al. 2016; Scholtes et al. 2012).

Studies investigating muscle performance in athletes with CP indicate that athletes with more severe impairments have impaired muscle power, more muscular imbalance and higher asymmetry in peak torque between limbs (Antunes et al. 2017). However, other studies report minor differences between affected and nonaffected sides of the body in elite hemiplegic CP athletes (Runciman et al. 2016c). This may indicate that training can support physiological adaptation and improve both the composition and function of muscles in athletes with CP (Antunes et al. 2017).

Verschuren and colleagues (2018) suggest that nutritional strategies such as appropriate energy intake, regular intake of high-quality protein across a day and sufficient protein to support muscle protein synthesis after a strength workout are relevant to prevent muscle loss in all individuals with CP. These recommendations align with current practise in sports nutrition.

7.3.3 Bone

Decreased bone mineral density (BMD) has been frequently documented in children and adults with CP (Finbråten et al. 2015; Fowler et al. 2015; Marciniak et al. 2016; Peterson et al. 2015). Contributing factors include low calcium intake, low vitamin D status, reduced weight-bearing and use of anticonvulsants (Fowler et al. 2015; Henderson et al. 2005; Houlihan and Stevenson 2009). Mobility is closely associated with BMD, with people who ambulate independently having higher BMD (Alvarez Zaragoza et al. 2018; Tosun et al. 2016). For people with CP who have limited mobility, maintaining a healthy body weight and a good calcium and vitamin D status are essential (Scarpato et al. 2017).

Few studies have investigated bone density in athletes with CP. Runciman and colleagues (2016c) measured the BMD of six male elite Paralympic athletes with CP. All participants were track sprinters with hemiplegic CP (5 with spastic hemiplegic CP and one with athetoid hemiplegic CP). This small investigation found no significant difference in BMD Z-scores between nonaffected and affected sides of the athletes. The participants also had BMD Z-scores above that of age- and sex-matched able-bodied individuals in the control database. The differences were not statistically significant; however, the authors speculate that high levels of athletic training over many years may result in physiological adaptation towards able-bodied levels.

7.3.4 Body Composition Assessment

A variety of methods are used to assess body composition in athletes, including surface anthropometry, bioelectrical impedance analysis (BIA), dual energy x-ray absorptiometry (DXA) and ultrasound (Ackland et al. 2012). While limited validation of these methods in CP populations has been conducted, current data suggest that a variety of body composition assessment methods have application for athletes with CP. In some cases, measurement techniques may need to be modified to suit the physical characteristics of individuals to detect changes in body composition over time. For more detailed discussion on this, please refer to Chapter 13.

7.3.4.1 Height

The standard way to measure height is via the stretch stature method using a calibrated stadiometer (Stewart et al. 2011). Sitting height can be measured if standing is not possible. Supine length can be measured if the athlete can lie in a straight position with appropriate limb alignment (Andrew and Sullivan 2010). Alternatively, lower leg length and knee height can be used to indicate linear growth (Andrew and Sullivan 2010).

7.3.4.2 Surface Anthropometry

The standard International Society for the Advancement of Kinanthropometry (ISAK) technique is to take skinfold measures on the right side of the body (Stewart et al. 2011). However, for athletes with CP, it is more useful to take measures on the dominant side of the body or both sides of the body. Measuring a sum of seven or eight skinfold sites is standard practise in sport; however, there might be cause to modify the sites according to an athlete's individual characteristics. For example, biceps, triceps, subscapular and abdominal sites may be most appropriate in an athlete with CP who uses a wheelchair. The critical factor is to consistently use a standardised protocol appropriate for each individual in order to track changes in body composition over time. It is useful to note that triceps skinfold thickness below the 10th percentile is an indicator of undernutrition in children with CP (Samson-Fang and Stevenson 2000). This might be relevant if working with athletes severely affected by CP such as boccia athletes. Compared to normally developing children, those with severe CP may have more intra-abdominal fat rather than subcutaneous fat (Peterson et al. 2015). This may make methods such as DXA and BIA more relevant than skinfold measurements for some athletes (Rieken et al. 2011), or alternatively the inclusion of a minimum waist girth would be valuable. However, the impact of spasticity on DXA and BIA measurements needs to be considered.

7.3.4.3 Dual Energy X-Ray Absorptiometry

DXA measures the absorption of x-ray beams by the body to determine the amount of bone mineral content, fat and fat free mass (FFM) in the body (Nana et al. 2015) and is the most common method to assess bone density. The neck of the femur and

L1–L4 vertebrae are typical measurement sites (Schousboe et al. 2013). However, for some athletes, the forearm or distal femur might be more practical (Harcke et al. 1998; Marciniak et al. 2016; Morse et al. 2009).

The use of DXA has been validated for use in children with altered body posture (Henderson et al. 2001) and is considered by many to be the reference method for measuring body composition in people with CP (Andrew and Sullivan 2010; Juzwiak et al. 2016; Scarpato et al. 2017). It may be necessary to modify the scanning position in athletes with altered posture, and scanning might not be possible for athletes who find it difficult to control movement.

7.3.4.4 Bioelectrical Impedance Analysis

BIA measures the resistance of an electrical current/s through the body to evaluate body water and fat free mass (Raymond et al. 2018). BIA assumes the body is a symmetrical configuration, hence postural abnormalities such as scoliosis and contractures can complicate BIA measurement in people with CP (Rieken et al. 2010). Some studies indicate that BIA can be used successfully in CP populations if the measurement method is modified. For example, Azcue et al. (1996) were able to measure children who could not relax their arms or legs by leaving the electrodes in place, repeating measurements every minute, up to a maximum of 10 times to provide a distribution of values. A review of studies comparing the use of BIA in children with CP against other methods of body composition assessment such as DXA found some support for BIA (Rieken et al. 2010). However, the studies were all limited by small sample sizes and were not undertaken in athletes, where small changes in body composition can result in meaningful performance benefits.

7.3.4.5 Body Fat

While many children with CP are underweight, it is also possible for people with CP to be overweight. There is evidence of accelerated central body fat deposition in adults with CP, and it is not clear if this can be addressed by diet and activity (Gillett et al. 2018). If body fat reduction is required, it can be difficult for athletes with impaired mobility to increase activity level without causing undue fatigue. This may necessitate a greater focus on dietary modification to reduce excess body fat. It can be challenging to maintain a nutritionally adequate and satisfying intake within a low energy budget. Therefore, the need for body fat reduction should be objectively assessed relative to the sport and potential impact on performance, and realistic goals developed.

COMMENTARY BOX 7.1

PHYSIOTHERAPIST'S INSIGHT: What have you learned about working with athletes with CP?

> You often need to think outside the box and put a little more thought into planning their training and what can optimise it. There often is no recipe, and you need to ensure you individualise each athlete's programme. There are varied presentations in CP (e.g. ataxic, spastic, dyskinetic, mixed presentations, etc.),

with each of these presentations perhaps responding differently to different stimuli. It can sometimes be a trial-and-error approach, as what may work really well with one athlete may in fact be detrimental to another.

Working with athletes with CP means you are forever being challenged and learning new things! It is a journey for both you and your athlete. But the things you learn together can also have a huge positive impact for their life outside sport.

Victoria Moore, Para-Athletics Sports Science & Sports Medicine Coordinator & Para-Athletics Lead Physiotherapist, Australia

7.4 ENERGY

7.4.1 Energy Requirements

The challenges associated with estimating energy requirements are amplified for athletes with CP. Athletes with CP have great variability in growth, body composition, muscle function, movement patterns and functional capacity. Hence, conventional standards for predicting energy requirements have limited application for people with CP (Azcue et al. 1996; Blauwet et al. 2017; Johnson et al. 1997). Currently, no clear evidence-based guidelines exist for estimating energy requirements in different CP populations (Scarpato et al. 2017).

In some situations, energy expenditure in people with CP may be higher than anticipated. The presence of athetosis, spasticity or ataxia may increase energy requirements (Blauwet et al. 2017; Jonsson et al. 2008; Juzwiak et al. 2016). Some estimates propose that spasticity may increase energy expenditure in the region of 10% of total energy expenditure (Krick et al. 1992). Ambulant people with CP may have higher energy expenditure due to greater inefficiency of muscle action when mobilising (Bratteby Tollerz et al. 2015).

In other situations, energy expenditure in people with CP may be lower than anticipated due to lower skeletal muscle mass or reduced activity (Andrew and Sullivan 2010; Krick et al. 1992). Studies of children with spastic quadriplegic CP have been shown to have lower resting energy expenditure and total energy expenditure than unaffected children (Azcue et al. 1996; Bratteby Tollerz et al. 2015; Stallings et al. 1996). Ambulatory status has a significant impact on energy expenditure (Johnson et al. 1997). Those with a higher level of mobility impairment are likely to have reduced energy needs.

Studies of energy expenditure in athletes with CP are limited. However, Juzwiak and colleagues (2016) measured resting metabolic rate (RMR) in eight Paralympic track and field athletes with CP who competed at the 2012 London Paralympic Games. The sample included athletes with mixed symptoms (five hypertonic, one ataxic, two athetotic). In this small population, RMR was 105 ± 3 kJ/kgFFM/day (25 ± 0.7 kcal/kgFFM/day) for three males and 105 ± 15 kJ/kgFFM/day (25 ± 3.5 kcal/kgFFM/day) for five females. These values were similar to other categories of Paralympic athletes measured at the same time.

Due to the diverse nature of athletes with CP, the best option is to directly measure energy expenditure where possible (Scarpato et al. 2017). Prediction equations for estimating energy requirements typically overestimate energy requirements in a variety of CP populations (Andrew and Sullivan 2010; Azcue et al. 1996; Krick et al. 1992; Rieken et al. 2011). Juzwiak et al. (2016) found when comparing measured versus predicted RMR in track and field athletes with CP, mean predicted RMR values obtained from all equations were higher than mean measured values. In this small population, Owen's and Mifflin equations were identified as providing the closest estimate of RMR (Juzwiak et al. 2016; see Table 3.1 for description of these equations). FFM was estimated through converting skinfolds to body density, and it is possible that predicted RMR may have more closely matched measured if an average FFM was determined from both sides of the body or if DXA was used to determine FFM.

7.4.2 Energy Availability

Low energy availability (LEA) is a mismatch between an athlete's energy intake and the energy expended in exercise, leaving inadequate energy to support the functions required by the body to maintain optimal health and performance, as outlined in Chapter 4. LEA can interfere with reproductive function and bone health and increase the risk of injury and illness in athletes. Some athletes experience LEA because of intentional restriction of energy intake, while for others LEA may occur inadvertently due to heavy training loads or lifestyles that make it challenging to consume adequate food. To date, limited investigation of energy availability in athletes has occurred, and clear thresholds for diagnosing low energy availability in athletes with CP have not been established. Nevertheless, there is reasonable cause to assume that athletes with CP are likely to be affected by low energy availability and related symptoms (Blauwet et al. 2017). As previously outlined, individuals with CP may have low BMD, which may limit its use as a marker of LEA. There is also evidence of menstrual dysfunction, with one study reporting approximately 29% of adolescents with CP experienced menstrual dysfunction (Burke et al. 2010). Menstrual dysfunction may be a direct consequence of a disrupted hypothalamic-pituitary axis caused by the original CP brain injury, or it could be a consequence of low energy availability (Colantonio et al. 2010; Ripley et al. 2008). There is a need to investigate the prevalence of LEA in athletes with CP as well as a need to educate athletes, coaches and support staff about the potential health and performance implications (Blauwet et al. 2017). A better understanding of energy requirements, energy expenditure and body composition in athletes with CP is pivotal to this.

7.5 FATIGUE AND RECOVERY

Fatigue is considered a common feature associated with CP (Brunton and Rice 2012). Anecdotally, athletes with CP require more time to recover between training sessions. Furthermore, athletes with CP and ABI can experience greater muscle spasticity and tonicity with fatigue, which ironically will increase energy expenditure and prolong the recovery period. Children with CP reportedly experience earlier onset of fatigue due to lower maximal oxygen consumption (Maltais et al. 2004a,b; Unnithan et al. 1998), or it may be an inherent feature of CP. It has been proposed that high muscle tone (spasticity) reduces venous return and inhibits lactate clearance during exercise, which increases local muscle fatigue and lowers endurance (Unnithan et al. 1998). One study investigated soccer-specific endurance, running economy and kinematic running criteria in elite athletes with CP (Kloyiam et al. 2011). Subjects were 18–40-year-olds with spastic diplegic CP who undertook 8 to 9 hours of soccer training per week and had competition experience ranging from 1 to 8 years. Lower soccer-specific endurance was found in the subjects with CP compared with reference values of soccer players without an impairment.

COMMENTARY BOX 7.2

COACH'S INSIGHT: What are the biggest differences in coaching Para athletes compared to able-bodied athletes?

> The general training concept and structure is the same; however, with CP, the athlete will fatigue more quickly. Furthermore, the specific strength exercises you may prescribe will be different as you have to balance their muscle structure and function and balance in an athlete with CP, and this will be very individual.

Iryna Dvoskina, Athletics (track) coach of multiple Paralympic medallists.

Studies that have directly measured fatigue in people with CP have produced interesting findings, with some suggesting that people with CP may have greater muscle fatigue resistance (Kloyiam et al. 2011). Moreau and colleagues (2008) tested muscle fatigue in the knee flexors and extensors in people with CP compared to those without a motor impairment. They found that the knee flexors and extensors in participants with CP were observed to be less fatigable than an age-matched comparison group as indicated by a lower rate of decline in peak torque. Differences in muscle composition may partly explain the fatigue resistance observed in some study designs (Brunton and Rice 2012). An increased area of type I muscle fibres or atrophy of type II fibres has been observed in people with CP (Rose et al. 1994). This could explain the combination of decreased strength plus fatigue resistance observed in some studies (Brunton and Rice 2012).

More recently, Runciman and colleagues (2015, 2016a,b,c) investigated fatigue in athletes with CP via sprint cycling, sprint running and vertical jump tests. These investigations involved small numbers of athletes; however, they indicated that athletes with CP fatigue similarly to able-bodied athletes. The investigators propose that high-level training results in athletes with CP exhibiting similar performance characteristics to able-bodied controls. Emerging evidence regarding the fatigue characteristics of athletes with CP may challenge existing ideas about recovery requirements and achievable training loads. However, Brunton and Rice (2012) point out that measurement of fatigue in laboratory settings does not reflect the chronicity of fatigue. It is possible for individuals with CP to have greater resistance to fatigue in the laboratory but still experience a greater subjective feeling of fatigue and a more significant impact of fatigue on daily activity. Further investigation of fatigue and optimal recovery is required for athletes with CP.

7.5.1 Injury Risk

Athletes with CP may be more at risk of injury due to long-standing impairments (Webborn and Van de Vliet 2012). Some reports indicate that athletes with CP often have injuries involving the knee and foot due to spasticity and altered gait (Klenck and Gebke 2007). Other sources indicate that overall injury rates in Paralympic athletes are comparable to able-bodied athletes (Fagher et al. 2016). Data from the 2012 Paralympic Games shows that Incident Rate (IR per 1000 athlete-days) for injuries in athletes with CP was lower than for other athlete categories in track (10.2) and field events (15.5; Blauwet et al. 2016). The authors found that ambulant athletes with CP were less likely to experience injuries in track disciplines (IR 10.2) compared to ambulant athletes who were either amputees (IR 29.8) or vision impaired (IR 23.1). One suggestion is that athletes with CP may be protected from lower extremity injuries as increased muscle tone may prohibit full, forceful eccentric muscle contraction during sprints and distance running events (Blauwet et al. 2016).

7.5.2 Pain

Pain occurs in up to 80% of individuals with a brain injury (Runciman and Derman 2018). This pain may be related to the neuromuscular consequences of brain injury rather than the neurological damage itself, and is often poorly managed. Pain can influence appetite and the desire to mobilise outside of the sporting environment and should be considered as a potential influencer of behaviour. Medications may be used to manage pain in athletes with CP, which can potentially interact with nutrition, as outlined in Chapter 12. However, there are many nonpharmacological treatments including Botox injections for muscle spasm, physical therapy and surgical interventions which should be discussed with the athlete's support team (Runciman and Derman 2018).

COMMENTARY BOX 7.3

PHYISOTHERAPIST'S INSIGHT: Is there anything you need to do differently with athletes with CP?

The importance of recovery strategies are paramount, and should never be neglected in a Para-athlete with CP. They often fatigue quicker; take longer to recover from training sessions, especially those that typically aggravate tone patterns.(i.e. velocity/speed); don't cope as well in heat/humid environments; take longer to recover from travel (especially when time zones are crossed) and are more likely to have other comorbidities (e.g. epilepsy, mental/auditory/vision impairments). This all needs to be taken into account, with strict recovery protocols designed for each athlete and written into their plans. Including things like sleep hygiene, wearing of compression garments (often very useful in limbs affected by tone), hot/cold water submersion programmes, pool recovery, PNF stretching and activation programmes, good nutrition etc.

It's also crucial to look at everything they are doing outside normal "training," for example, studying/prolonged concentration, stress, increased walking, prolonged sitting, as this often has a much larger effect on them than their able-bodied counterparts. They suffer far more from both mental and physical fatigue, and their recovery may need to be increased and training sessions altered accordingly. You need to consider their overall load, not just their training load!

Victoria Moore, Para-Athletics Sports Science & Sports Medicine Coordinator & Para-Athletics Lead Physiotherapist, Australia

7.6 NUTRITIONAL NEEDS

Recommendations for macro- and micronutrient intake generally align with those of able-bodied athletes. Intake should be individualised and matched to workload, sport/training load, adaptation goals and body composition goals, as outlined in Chapter 3.

7.6.1 Carbohydrate and Fibre

Currently, no data is available regarding the capacity of muscle in athletes with CP to recover and optimise muscle glycogen stores. It is possible that carbohydrate requirements and capacity for glycogen storage are reduced in people more severely affected by CP where substantial muscle atrophy is present; however, this remains untested. Athletes with altered gastrointestinal motility may benefit from additional fibre in combination with adequate fluid intake. Trial and error are required to determine the optimal intake for each individual athlete.

7.6.2 Protein

Athletes with more severe impairment may have reduced capacity for muscle protein synthesis and therefore require less protein. Conversely, if it is shown that individuals with CP have accelerated muscle ageing, this may warrant a higher protein intake (Verschuren et al. 2018). In the absence of specific guidelines, protein intake should at least be similar (per kg/FFM) to able-bodied athletes.

COMMENTARY BOX 7.4

COACH'S INSIGHT: What sports nutrition practises have had the biggest impact on the training capability or performance of your athletes?

> Recovery! Recovery is more specific to many athletes with an impairment. For example, in CP, the recovery of the nervous system is crucial to help them train effectively session after session and can take longer than in an AB athlete. If their nervous system does not recover quickly, they will tend to spasm more, which disrupts their sleep and further delays recovery.

Iryna Dvoskina, Athletics (track) coach of multiple Paralympic medallists.

7.6.3 Fat

Fat intake should be treated the same as for all athletes – primarily unsaturated sources within an individual's energy budget. Athletes with higher energy needs may benefit from additional fat (oils, nut pastes, avocado, etc.) to reduce the volume of food that needs to be consumed.

Athletes with CP may also have epilepsy. A ketogenic (very low carbohydrate) diet has been shown to minimise the symptoms of epilepsy or seizure disorders in those who are refractory to medications (Kossoff et al. 2018; Masino and Rho 2018). The suitability of this in an athlete population needs to be assessed individually in conjunction with an experienced sports dietitian, with careful consideration regarding the essential role of carbohydrate in supporting moderate to high-intensity exercise, immune function, tolerance of heavy training loads and neural functioning.

KETO CASE STUDY

Case study – female international-level thrower (F51 class), quadriplegic.

Concussion injury, treated acutely with fish oil supplementation. Experienced ongoing neurological issues 10 months following concussion, which was diagnosed as seizures by neurologist. Treated with medications, but continued to experience seizures on a regular basis. Neurologist recommended trialling ketogenic diet.

Initial goal <40 g/day digestible carbohydrate (contribution of fibre accounted for). Successfully achieved 30–40 g/day carbohydrate with moderate ketones in urine for over 2 months, which together with adjustment to medication was successful in reducing duration and severity of seizures. However, reported difficulty completing training programme, both throws and strength work. Consequently, adjusted carbohydrate intake to prioritise pretraining period in order to provide sufficient blood glucose for high-intensity efforts.

Following 6 months of ketogenic diet, seizure symptoms had diminished sufficiently for neurologist to agree to a slow increase in dietary carbohydrate intake. Suggested goal was increasing 5 g every 2 weeks to a target of 60 g/day digestible carbohydrate.

Athlete was lost to follow-up due to medical issues unrelated to the ketogenic diet.

7.6.4 Micronutrients

Standard recommendations for consumption of vitamins, minerals and trace elements should be followed. Low vitamin D status has been observed in CP populations where anticonvulsant drugs are used or sunlight exposure is insufficient (Fehlings et al. 2012; Le Roy et al. 2018). In cases where feeding or swallowing difficulties are present, micronutrient deficiency is more likely, and supplementation should be considered (Scarpato et al. 2017).

7.6.5 Fluid

Some athletes with CP have altered hypothalamic function, which can increase the likelihood of thermoregulatory problems (Simon and Ward 2014). Following a stroke, increased sweating and decreased skin temperature have been observed on the affected side of the body compared to the nonaffected side (Korpelainen et al. 1993). It is possible (but unproven) that this also applies to people with CP and potentially ABI. Furthermore, it has been proposed that people with CP may generate more metabolic heat while exercising due to impaired exercise economy and this might exacerbate heat stress (Maltais et al. 2004b).

Minimal investigation of thermoregulation and fluid requirements has been undertaken in athletes with CP to date. Two studies in children found no difference in sweat rates or thermal strain in subjects with mild-moderate CP when exercising in the heat compared to controls (Maltais et al. 2004a,b). Workload was moderate in these studies, and it is possible that differences might have been observed under greater stress.

There is no firm evidence that athletes with CP have different fluid needs from other athletes. However, athletes with communication or cognitive disorders might not readily report symptoms of heat or cold intolerance (Webborn & Van de Vliet 2012). Athletes with convulsive disorders are more likely to experience convulsions if overly fatigued, stressed or dehydrated (Webborn 1996). Practically, some athletes with CP may require closer supervision and assistance with fluid intake when exercising in the heat.

7.7 FOOD PREPARATION AND COOKING

Athletes mildly affected by CP generally cope well with food preparation and cooking. However, it is useful to be alert to athletes who report their CP has little impact on their lives yet make subtle modifications such as relying heavily on preprepared food. It is essential to ensure such athletes have a high-quality diet with sufficient variety. Advice about using products such as par-cooked rice, frozen vegetable mixes, prechopped animal proteins and fresh vegetables and enhancing frozen meals can be useful.

Athletes with CP may not have seen health providers such as occupational therapists since they were quite young. Some older athletes may be dismissive of the need to seek support. Sports nutrition professionals may find it useful to speak with an occupational therapist and be abreast of aids that can help with tasks such as meal preparation. Tools to help with gripping food while chopping or opening food packages can help speed up meal preparation time (see Chapter 15 for examples).

Athletes more severely affected by CP are likely to require additional support at meal times. Some may have physical feeding difficulties and require assistance with meals. Meal times may take longer and the process of eating may be quite messy (Crosland and Boyd 2014). Athletes may also have long-term food aversions that have been part of the athletes' life since childhood. For example (Crosland and Boyd 2014):

- Difficulty eating new textures
- Increased sensory sensitivity
- Aversion to accepting new foods
- Poor tolerance of certain colours or packaging
- Dislike of certain temperatures (e.g. hot or cold food)

If not managed appropriately, this could compromise nutritional adequacy and create unnecessary stress during residential training camps and competitions. It is important that those with feeding problems have appropriate help from staff or carers to assist them at meal times. Staff must handle this practically and sympathetically (Crosland and Boyd 2014).

Where feeding difficulties are significant and nutritional intake substantially restricted, food supplements may be warranted to support nutritional intake. A small number of athletes may use enteral feeding, usually via a gastrostomy tube – an artificial tract created between the stomach and the abdominal surface (Crosland and Boyd 2014). When working with an athlete using supplements or enteral feeding, it is vital that medical/clinical advice be sought. These individuals will normally have a support team including a doctor, clinical dietitian and nurse, who should be integrated into the overall support team for the athlete. The key message for the sports nutrition practitioner is the importance of individuality and the need to work carefully with other team members involved in the care and training of the athlete.

7.8 TRAVEL

Long periods of travel can be additionally uncomfortable for athletes with altered posture or impaired movement. Rapid change of climate and time zone may affect athletes with CP more than nonaffected athletes. For some athletes, risk of convulsion can be higher when faced with the additional demands of travel. The impact of travel will be highly individual. However, some athletes with CP may require more time to acclimatise and recover from the journey.

Eating in public, especially large dining room-style environments may challenge some athletes. Athletes with fine motor impairment may prefer not to eat in public. Some require assistance accessing food and opening packages. Any support needs to be provided sensitively.

7.9 SUPPLEMENTS

Very few supplements have been tested in athletes with CP, but anecdotally, elite athletes with CP are just as interested as other athletes in using ergogenic aids. Potentially, supplements such as creatine, caffeine, bicarbonate, beta-alanine and beetroot juice can benefit some athletes with CP. The appropriateness of a supplement depends on the event and the training level of the athlete more so than whether the athlete has CP, as outlined in Chapter 14. The individual needs and characteristics of each athlete should be considered when making decisions about supplements. Bear in mind that some athletes with CP require multiple medications for co-mitigating conditions which may interact with supplements as outlined in Chapter 12.

7.10 CONCLUSION

CP is a permanent brain injury present at birth, whereas ABI can be acquired at any stage in life. These conditions affect movement and posture in myriad ways. While the original conditions are not progressive, the symptoms of both CP and ABI can change over time. In many cases, these athletes are very similar to able-bodied athletes. Others might have entirely different needs. Sports nutrition professionals need to work with athletes, coaches and other support staff to identify the way CP and ABI impact each athlete and determine the most appropriate individualised approach to their nutrition plans.

KEY MESSAGES

- Athletes with CP and ABI compete in a range of sports and have diverse requirements – there are no generic nutrition recommendations for athletes with CP or ABI.
- Sports dietitians working with athletes with CP and ABI need to work closely with other support staff (medicine, physiotherapy, physiology) to fully understand the requirements of each individual.
- Nutritional assessment must be individualised – sports dietitians/nutritionists may need to work in conjunction with clinical dietitians for some athletes.
- Some athletes with CP have impaired growth and altered body composition; however, emerging evidence suggests that high-level training can result in athletes with CP exhibiting similar body composition and performance characteristics to able-bodied controls.
- Estimating energy requirements can be challenging, as some CP and ABI symptoms increase energy requirements, whereas as others decrease energy

requirements. Mobility, body composition and training levels are important considerations when assessing energy requirements.
- Theoretically, ergogenic aids should have similar effects in athletes with CP or ABI; however, individual testing and adjustment is needed, especially where interactions with medications are possible.
- Athletes with CP may require support to manage feeding difficulties and food aversions – these issues need to be handled sensitively.

SPECIAL COMMENTARY: POST-TRAUMATIC STRESS DISORDER

Post-traumatic stress disorder (PTSD) is a disorder that develops in some individuals who have experienced a shocking, traumatic, scary or dangerous event. A substantial number of Para athletes have acquired their impairment as a consequence of such events; hence, PTSD can be a factor that the practitioner should be aware of.

While the diagnosis and treatment of PTSD are beyond the scope of this book, it is important for practitioners to be aware of the recurring symptoms, behaviours and experiences that can manifest as a consequence of chronic PTSD. In particular, when travelling with a team of athletes, practitioners should be aware of the potential triggers to PTSD for individuals, so that any unusual behaviour and reactions can be supported effectively.

PTSD is diagnosed when symptoms from four key areas are experienced by an individual:

1. Re-experiencing symptoms:
    - Nightmares/bad dreams
    - Flashbacks – reliving the trauma, including physical symptoms such as increased heart rate or sweating
    - Frightening thoughts
2. Avoidance symptoms:
    - Staying away from objects, events or places that are reminders of the experience
    - Avoiding thoughts or feelings related to the experience
3. Arousal and reactivity symptoms:
    - Difficulty sleeping
    - Feeling “on edge”
    - Being easily startled
    - Self destructive behaviour
    - Difficulty concentrating
    - Angry outbursts
4. Cognition and mood symptoms:
    - Difficulty remembering key features of the traumatic event
    - Difficulty maintaining close relationships and feeling detached from family and friends

- Negative thoughts about oneself or the world
- Distorted feelings like guilt or blame
- Loss of interest in enjoyable activities

Athletes with chronic PTSD are likely to experience variable intensities and frequency of their symptoms and if diagnosed effectively, may be on medications. It is important for practitioners to be aware of changes in personality and behaviour in order to be sensitive to potential triggers and also to consider the potential impact of these on nutrition interventions and needs. Building trusting relationships with some athletes may take longer and practitioners need to be flexible and patient.

REFERENCES

Ackland, T.R., Lohman, T.G., Sundgot-Borgen, J. et al. 2012. Current status of body composition assessment in sport: Review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical Commission. *Sports Medicine* 42:227–249.

Akhter, N., Khan, A.A. and Ayyub, A. 2017. Motor impairment and skeletal mineralization in children with cerebral palsy. *The Journal of the Pakistan Medical Association* 67:200–203.

Alvarez Zaragoza, C., Vasquez Garibay, E.M., García Contreras, A.A. et al. 2018. Bone mineral density and nutritional status in children with quadriplegic cerebral palsy. *Archives of Osteoporosis* 13:17.

Andrew, M.J. and Sullivan, P.B. 2010. Growth in cerebral palsy. *Nutrition in Clinical Practice* 25:357–361.

Antunes, D., Rossato, M., Kons, R.L., Sakugawa, R.L. and Fischer, G. 2017. Neuromuscular features in sprinters with cerebral palsy: Case studies based on Paralympic classification. *Journal of Exercise Rehabilitation* 13:716–721.

Australian Paralympic Committee. 2018. Para-athletics – Classification. https://www.paralympic.org.au/sport/para-athletics/ (Last accessed August 2018).

Azcue, M.P., Zello, G.A., Levy, L.D. and Pencharz, P.B. 1996. Energy expenditure and body composition in children with spastic quadriplegic cerebral palsy. *Journal of Pediatrics* 129:870–876.

Barrett, R. and Lichtwark, G. 2010. Gross muscle morphology and structure in spastic cerebral palsy: A systematic review. *Developmental Medicine and Child Neurology* 52:794–804.

Beckman, E.M., Connick, M.J. and Tweedy, S.M. 2017. Assessing muscle strength for the purpose of classification in Paralympic sport: A review and recommendations. *Journal of Science and Medicine in Sport* 20:391–396.

Bell, K.L., Boyd, R.N., Tweedy, S.M., Weir, K.A., Stevenson, R.D. and Davies, P.S. 2010. A prospective, longitudinal study of growth, nutrition and sedentary behaviour in young children with cerebral palsy. *BMC Public Health* 10:179.

Blauwet, C.A., Brook, E.M., Tenforde, A.S. et al. 2017. Low energy availability, menstrual dysfunction, and low bone mineral density in individuals with a disability: Implications for the Para athlete population. *Sports Medicine* 47:1697–1708.

Blauwet, C.A., Cushman, D., Emery, C. et al. 2016. Risk of injuries in Paralympic track and field differs by impairment and event discipline: A prospective cohort study at the London 2012 Paralympic Games. *American Journal of Sports Medicine* 44:1455–1462.

Bratteby Tollerz, L.U., Forslund, A.H., Olsson, R.M., Lidström, H. and Holmbäck, U. 2015. Children with cerebral palsy do not achieve healthy physical activity levels. *Acta Paediatrica* 104:1125–1129.

Brunton, L.K. and Rice, C.L. 2012. Fatigue in cerebral palsy: A critical review. *Developmental Neurorehabilitation* 15:54–62.

Burke, L.M., Kalpakjian, C.Z., Smith, Y.R. and Quint, E.H. 2010. Gynecologic issues of adolescents with down syndrome, autism, and cerebral palsy. *Journal of Pediatric and Adolescent Gynecology* 23:11–15.

Colantonio, A., Mar, W., Escobar, M. et al. 2010. Women's health outcomes after traumatic brain injury. *Journal of Women's Health* 19:1109–1116.

Colver, A., Fairhurst, C. and Pharoah, P.O. 2014. Cerebral palsy. *Lancet* 383:1240–1249.

Coniglio, S.J., Stevenson, R.D. and Rogol, A.D. 1996. Apparent growth hormone deficiency in children with cerebral palsy. *Developmental Medicine and Child Neurology* 38:797–804.

CPARF (Cerebral Palsy Alliance Research Foundation). 2018. About Cerebral Palsy. https://research.cerebralpalsy.org.au (Last accessed August 2018).

Crosland, J. and Boyd, C. 2014. Cerebral palsy and acquired brain injuries. In *Sports Nutrition for Paralympic Athletes*, ed. Broad, E. pp. 91–105. Boca Raton: CRC Press.

Fagher, K., Forsberg, A., Jacobsson, J., Timpka, T., Dahlström, Ö. and Lexell, J. 2016. Paralympic athletes' perceptions of their experiences of sports-related injuries, risk factors and preventive possibilities. *European Journal of Sport Science* 16:1240–1249.

Fehlings, D., Switzer, L., Agarwal, P. et al. 2012. Informing evidence-based clinical practice guidelines for children with cerebral palsy at risk of osteoporosis: A systematic review. *Developmental Medicine and Child Neurology* 54:106–116.

Finbråten, A.K., Syversen, U., Skranes, J., Andersen, G.L., Stevenson, R.D. and Vik, T. 2015. Bone mineral density and vitamin D status in ambulatory and non-ambulatory children with cerebral palsy. *Osteoporosis International* 26:141–150.

Fowler, E.G., Rao, S., Nattiv, A., Heberer, K. and Oppenheim, W.L. 2015. Bone density in premenopausal women and men under 50 years of age with cerebral palsy. *Archives of Physical Medicine and Rehabilitation* 96:1304–1309.

Gillett, J.G., Lichtwark, G.A., Boyd, R.N. and Barber, L.A. 2018. Functional capacity in adults with cerebral palsy: Lower limb muscle strength matters. *Archives of Physical Medicine and Rehabilitation* 99:900–906.

Hanna, S.E., Rosenbaum, P.L., Bartlett, D.J. et al. 2009. Stability and decline in gross motor function among children and youth with cerebral palsy aged 2–21 years. *Developmental Medicine and Child Neurology* 51:295–302.

Harcke, H.T., Taylor, A., Bachrach, S., Miller, F. and Henderson, R.C. 1998. Lateral femoral scan: An alternative method for assessing bone mineral density in children with cerebral palsy. *Pediatric Radiology* 28:241–246.

Henderson, R.C., Kairalla, J.A., Barrington, J.W., Abbas, A. and Stevenson, R.D. 2005. Longitudinal changes in bone density in children and adolescents with moderate to severe cerebral palsy. *Journal of Pediatrics* 146:769–775.

Henderson, R.C., Lark, R.K., Renner, J.B. et al. 2001. Dual x-ray absorptiometry assessment of body composition in children with altered body posture. *Journal of Clinical Densitometry* 4:325–335.

Houlihan, C.M. and Stevenson, R.D. 2009. Bone density in cerebral palsy. *Physical and Medicine Rehabilitation Clinics of North America* 20:493–508.

International Executive Committee for the Definition of Cerebral Palsy. 2005. Proposed definition and classification of cerebral palsy. *Developmental Medicine and Child Neurology* 47:571–576.

International Paralympic Committee (IPC). 2015. IPC Athlete Classification Code Rules, Policies and Procedures for Athlete Classification July 2015. https://www.paralympic.org/sites/default/files/document/150813212311788_Classification%2BCode_1.pdf

Johnson, R.K., Hildreth, H.G., Contompasis, S.H. and Goran, M.I. 1997. Total energy expenditure in adults with cerebral palsy as assessed by doubly labeled water. *Journal of the American Dietetic Association* 97:966–970.

Jonsson, A.C., Lindgren, I., Norrving, B. and Lindgren, A. 2008. Weight loss after stroke: A population-based study from the Lund Stroke Register. *Stroke* 39:918–923.

Juzwiak, C.R., Winckler, C., Joaquim, D.P., Silva, A. and de Mello, M.T. 2016. Comparison of measured and predictive values of basal metabolic rate in Brazilian Paralympic track and field athletes. *International Journal of Sport Nutrition and Exercise Metabolism* 26:330–337.

Klenck, C. and Gebke, K. 2007. Practical management: Common medical problems in disabled athletes. *Clinical Journal of Sport Medicine* 17:55–60.

Kloyiam, S., Breen, S., Jakeman, P., Conway, J. and Hutzler, Y. 2011. Soccer-specific endurance and running economy in soccer players with cerebral palsy. *Adapted Physical Activity Quarterly* 28:354–367.

Korpelainen, J.T., Sotaniemi, K.A. and Myllylä, V.V. 1993. Asymmetric sweating in stroke: A prospective quantitative study of patients with hemispheral brain infarction. *Neurology* 43:1211–1214.

Kossoff, E.H., Zupec-Kania, B.A., Auvin, S. et al. 2018. Optimal clinical management of children receiving dietary therapies for epilepsy: Updated recommendations of the International Ketogenic Diet Study Group. *Epilepsia* 32:175–192.

Krick, J., Murphy, P.E., Markham, J.F. and Shapiro, B.K. 1992. A proposed formula for calculating energy needs of children with cerebral palsy. *Developmental Medicine and Child Neurology* 34:481–487.

Larner, A.J. 2016. *A Dictionary of Neurological Signs* (4th edn), London: Springer.

Le Roy, C., Barja, S., Sepúlveda, C. et al. 2018. Vitamin D and iron deficiencies in children and adolescents with cerebral palsy. *Neurologia* pii: S0213-4853(17)30372-9.

Maltais, D., Unnithan, V., Wilk, B. and Bar-Or, O. 2004a. Responses of children with cerebral palsy to arm-crank exercise in the heat. *Medicine and Science in Sports and Exercise* 36:191–197.

Maltais, D., Wilk, B., Unnithan, V. and Bar-Or, O. 2004b. Responses of children with cerebral palsy to treadmill walking exercise in the heat. *Medicine and Science in Sports and Exercise* 36:1674–1681.

Marciniak, C., Gabet, J., Lee, J., Ma, M., Brander, K. and Wysocki, N. 2016. Osteoporosis in adults with cerebral palsy: Feasibility of DXA screening and risk factors for low bone density. *Osteoporosis International* 27:1477–1484.

Masino, S.A. and Rho, J.M. 2018. Metabolism and epilepsy: Ketogenic diets as a homeostatic link. *Brain Research* pii: S0006-8993(18)30325-1.

Moreau, N.G., Li, L., Geaghan, J.P. and Damiano, D.L. 2008. Fatigue resistance during a voluntary performance task is associated with lower levels of mobility in cerebral palsy. *Archives of Physical Medicine and Rehabilitation* 89:2011–2016.

Morse, L.R., Lazzari, A.A., Battaglino, R. et al. 2009. Dual energy x-ray absorptiometry of the distal femur may be more reliable than the proximal tibia in spinal cord injury. *Archives of Physical Medicine and Rehabilitation* 90:827–831.

Nana, A., Slater, G.J., Stewart, A.D. and Burke, L.M. 2015. Methodology review: Using dual-energy x-ray absorptiometry (DXA) for the assessment of body composition in athletes and active people. *International Journal of Sport Nutrition and Exercise Metabolism* 25:198–215.

Opheim, A., Jahnsen, R., Olsson, E. and Stanghelle, J.K. 2009. Walking function, pain, and fatigue in adults with cerebral palsy: A 7-year follow-up study. *Developmental Medicine and Child Neurology* 51:381–388.

Parkes, J., White-Koning, M., Dickinson, H.O. et al. 2008. Psychological problems in children with cerebral palsy: A cross-sectional European study. *Journal of Child Psychology and Psychiatry* 49:405–413.

Peterson, M.D., Zhang, P., Haapala, H.J., Wang, S.C. and Hurvitz, E.A. 2015. Greater adipose tissue distribution and diminished spinal musculoskeletal density in adults with cerebral palsy. *Archives of Physical Medicine and Rehabilitation* 96:1828–1833.

Raymond, C.J., Dengel, D.R. and Bosch, T.A. 2018. Total and segmental body composition examination in collegiate football players using multifrequency bioelectrical impedance analysis and dual x-ray absorptiometry. *Journal of Strength and Conditioning Research* 32:772–782.

Rieken, R., Calis, E.A., Tibboel, D., Evenhuis, H.M. and Penning, C. 2010. Validation of skinfold measurements and bioelectrical impedance analysis in children with severe cerebral palsy: A review. *Clinical Nutrition* 29:217–221.

Rieken, R., van Goudoever, J.B., Schierbeek, H. et al. 2011. Measuring body composition and energy expenditure in children with severe neurologic impairment and intellectual disability. *American Journal of Clinical Nutrition* 94:759–766.

Ripley, D.L., Harrison-Felix, C., Sendroy-Terrill, M., Cusick, C.P., Dannels-McClure, A. and Morey, C. 2008. The impact of female reproductive function on outcomes after traumatic brain injury. *Archives of Physical Medicine and Rehabilitation* 89:1090–1096.

Rose, J., Haskell, W.L., Gamble, J.G., Hamilton, R.L., Brown, D.A. and Rinsky, L. 1994. Muscle pathology and clinical measures of disability in children with cerebral palsy. *Journal of Orthopaedic Research* 12:758–768.

Ross, S.M., MacDonald, M. and Bigouette, J.P. 2016. Effects of strength training on mobility in adults with cerebral palsy: A systematic review. *Disability and Health Journal* 9:375–384.

Runciman, P. and Derman, W. 2018. Athletes with brain injury: Pathophysiological and medical challenges. *Physical Medicine and Rehabilitation Clinics of North America* 29:267–281.

Runciman, P., Derman, W., Ferreira, S., Albertus-Kajee, Y. and Tucker, R. 2015. A descriptive comparison of sprint cycling performance and neuromuscular characteristics in able-bodied athletes and Paralympic athletes with cerebral palsy. *American Journal of Physical Medicine and Rehabilitation* 94:28–37.

Runciman, P., Tucker, R., Ferreira, S., Albertus-Kajee, Y. and Derman, W. 2016a. Paralympic athletes with cerebral palsy display altered pacing strategies in distance-deceived shuttle running trials. *Scandinavian Journal of Medicine and Science in Sports* 26:1239–1248.

Runciman, P., Tucker, R., Ferreira, S., Albertus-Kajee, Y. and Derman, W. 2016b. Effects of induced volitional fatigue on sprint and jump performance in Paralympic athletes with cerebral palsy. *American Journal of Physical Medicine and Rehabilitation* 95:277–290.

Runciman, P., Tucker, R., Ferreira, S., Albertus-Kajee, Y., Micklesfield, L. and Derman, W. 2016c. Site-specific bone mineral density is unaltered despite differences in fat-free soft tissue mass between affected and nonaffected sides in hemiplegic Paralympic athletes with cerebral palsy: Preliminary findings. *American Journal of Physical Medicine and Rehabilitation* 95:771–778.

Samson-Fang, L.J. and Stevenson, R.D. 2000. Identification of malnutrition in children with cerebral palsy: Poor performance of weight-for-height centiles. *Developmental Medicine and Child Neurology* 42:162–168.

Scarpato, E., Staiano, A., Molteni, M., Terrone, G., Mazzocchi, A. and Agostoni, C. 2017. Nutritional assessment and intervention in children with cerebral palsy: A practical approach. *International Journal of Food Science and Nutrition* 68:763–770.

Scholtes, V.A., Becher, J.G., Janssen-Potten, Y.J., Dekkers, H., Smallenbroek, L. and Dallmeijer, A.J. 2012. Effectiveness of functional progressive resistance exercise training on walking ability in children with cerebral palsy: A randomized controlled trial. *Research in Developmental Disabilities* 33:181–188.

Schousboe, J.T., Shepherd, J.A., Bilezikian, J.P. and Baim, S. 2013. Executive summary of the 2013 International Society for Clinical Densitometry Position Development Conference on bone densitometry. *Journal of Clinical Densitometry* 16:455–466.

Shim, M.L., Moshang, T. Jr., Oppenheim, W.L. and Cohen, P. 2004. Is treatment with growth hormone effective in children with cerebral palsy? *Developmental Medicine and Child Neurology* 46:569–571.

Simon, L.M. and Ward, D.C. 2014. Preparing for events for physically challenged athletes. *Current Sports Medicine Reports* 13:163–168.

Stallings, V.A., Zemel, B.S., Davies, J.C., Cronk, C.E. and Charney, E.B. 1996. Energy expenditure of children and adolescents with severe disabilities: A cerebral palsy model. *American Journal of Clinical Nutrition* 64:627–634.

Stevenson, R.D., Hayes, R.P., Cater, L.V. and Blackman, J.A. 1994. Clinical correlates of linear growth in children with cerebral palsy. *Developmental Medicine and Child Neurology* 36:135–142.

Stewart, A., Marfell-Jones, M., Olds, T. and de Ridder, H. 2011. *International Standards for Anthropometric Assessment*. New Zealand: ISAK.

Tosun, A., Erisen Karaca, S., Unuvar, T., Yurekli, Y., Yenisey, C. and Omurlu, I.K. 2016. Bone mineral density and vitamin D status in children with epilepsy, cerebral palsy, and cerebral palsy with epilepsy. *Childs Nervous System* 33:153–158.

Unnithan, V.B., Clifford, C. and Bar-Or, O. 1998. Evaluation by exercise testing of the child with cerebral palsy. *Sports Medicine* 26:239–251.

Van Der Slot, W.M., Nieuwenhuijsen, C., Van Den Berg-Emons, R.J. et al. 2012. Chronic pain, fatigue, and depressive symptoms in adults with spastic bilateral cerebral palsy. *Developmental Medicine and Child Neurology* 54:836–842.

Verschuren, O., Smorenburg, A.R.P., Luiking, Y., Bell, K., Barber, L. and Peterson, M.D. 2018. Determinants of muscle preservation in individuals with cerebral palsy across the lifespan: A narrative review of the literature. *Journal of Cachexia, Sarcopenia and Muscle* 9:453–464.

Webborn, A.D.J. 1996. Heat-related problems for the Paralympic Games, Atlanta 1996. *British Journal of Therapy and Rehabilitation* 3:429–436.

Webborn, N. and Van de Vliet, P. 2012. Paralympic medicine. *Lancet* 380:65–71.

8 Nutrition for Amputees

Jacque Scaramella

CONTENTS

8.1 INTRODUCTION

Despite 82% of all amputations resulting from vascular conditions; 16% due to trauma; and 2% the result of inflammatory causes, cancer or birth defects (Dillingham et al. 2002), US athletes with an amputation more commonly suffered a trauma, congenital malformation or cancer, rather than vascular causes. Physical activity and sport participation is important for amputees and is associated with favourable outcomes in a broad range of health parameters, including the cardiopulmonary system, mental well-being, social integration and general physical abilities (Bragaru et al. 2011).

Based on the Paralympic classification system (International Paralympic Committee 2015), athletes with an amputation fit into the impairment category of either limb deficiency or leg length difference. Limb deficiency is considered full or partial absence of bones or joints as a consequence of amputation due to illness, trauma or congenital limb deficiency (e.g., dysmelia). Athletes are classified not only relative to their impairment but also based on sport (as outlined in Chapter 2 and in Table 8.1).

8.2 CHARACTERISTICS AND PHYSIOLOGY OF ATHLETES WITH AN AMPUTATION

While most Paralympic sports allow prostheses in competition, they are not permitted in sled hockey, sitting volleyball or swimming events at international competitions.

Athletes with an upper-extremity amputation or limb deficiency can easily participate in most sports, with or without the use of an adaptive device. Adaptive equipment has improved to the level that amputees can participate in virtually any sport, regardless of the level of competition.

Skiing is very popular for amputees, partly due to the advanced technologies available, and speeds can equal those of their able-bodied counterparts. Due to stiff ski boots, below-knee (or transtibial) amputees (BKA) can ski using a prosthesis with either a multiaxial ankle or an ankle with a prefixed dorsiflexion. Those athletes with above-knee (or transfemoral) amputation (AKA) or hip disarticulation can use a three-track system with skis attached to crutches and a third ski on the intact leg. Alternatively, skiers with bilateral above-knee amputations or hip disarticulation can choose a monoski, which is mounted under a seat (or "bucket"; Bergeron 1999).

Cycling and triathlon are also popular sports for amputees since pedalling devices such as toe clips, which effectively lock the foot (prosthesis) to the pedal, facilitate the up and down strokes. The more proximal the amputation, the more likely the athlete will choose to ride without the prostheses.

COMMENTARY BOX 8.1

Different prosthetic devices:

> Numerous differences are noteworthy when comparing a cycling prosthetic and a sound limb or other styles of prosthetic legs. A prosthetic leg will not have any dorsiflexion, which affects both leg length and cleat placement. A cycling prosthetic will be longer than the opposing limb in order to overcome the lack of dorsiflexion. In comparison to a sound limb and an able-bodied cyclist, where the cycling cleat is located on the ball of the foot, the cleat on the affected side will fall further or directly under the knee to prevent a loss in power output. Another important factor in preserving power output is the rigidity of the leg as a whole. The leg should be designed from a light and rigid material to avoid any power losses through flex of the materials. One of the most important factors in power generation and comfortability is fit of the prosthetic socket. Because cycling is a non–weight bearing sport, the socket, especially the trim lines, are designed to promote mobility. Compared to a walking prosthetic, a cycling prosthetic's trim lines will be cut back further to allow for a natural range of motion because the leg is not required to provide the stability for weight bearing. In a cyclist with an above-knee amputation, a mechanical knee is not only desirable, but required, as rules prohibit electronic componentry. The mechanical knee should remain in an unlocked position at all times while cycling.

Allysa Seely, Paratriathlete and Gold Medallist at the 2016 Paralympic Games

TABLE 8.1
Para Sport Classifications for Amputees

Sport	Classification	Description
Para Alpine Skiing	LW 1	Impairments that strongly affect *both* legs (i.e., above-knee amputees and muscle weakness)
	LW 2	Impairment in only one leg (i.e., amputee or birth defect)
	LW 3	Moderate impairment in *both* legs (i.e., below-knee amputee and muscle weakness)
	LW 4	Impairment in one leg only, but fewer activity limitations (i.e., below-knee amputee)
	LW 5/7	Impairment in both arms, (i.e., arm amputee, loss of muscle power)
	LW 6/8	Impairments in only one arm
	LW 12	Normal trunk function and leg impairments; Sport Classes LW1-4 can fit in this sport class and may choose to ski standing or sitting at the start of their career
Athletics	T42-44 & F42-44	Compete without prosthesis affected by limb deficiency, leg length difference, impaired muscle power or impaired passive range of movement
	T45-47 & F45-46	Upper limb(s) affected by limb deficiency, impaired muscle power or impaired passive range of movement
	T51-54	Compete using a racing wheelchair, (i.e., limb deficiency, leg length difference, impaired muscle power or impaired passive range of movement)
	F51-57	Seated throws: that is, limb deficiency, leg length difference, impaired muscle power or impaired range of movement
	T61-64 & F61-64	Lower limb(s) competing with prosthesis affected by limb deficiency and leg length difference
Archery	Open (W2 & ST)	Activity limitations in trunk and legs and may compete in a wheelchair or standing; arms show normal function (i.e., leg length difference, limb deficiency, paraplegic)
Badminton	WH 2 (wheelchair)	Impairment in one or both lower limbs and minimal to no impairment of the trunk, (i.e., loss of one or two legs above the knee and spinal cord injuries)
	SL 3 (standing)	Impairment in one or both lower limbs and poor walking/running balance; play half court (i.e., cerebral palsy or loss of both legs below the knee)
	SL 4 (standing)	Impairment in one or both lower limbs, but have better balance and run faster compared to SL 3; play full court
	SU 5 (standing)	Impairment in upper limbs only; mild impairment in the playing hand or a severe impairment to the nonplaying arm impacting abilities to serve (i.e., loss of an arm or arm without function due to nerve damage)
Biathlon and Cross-Country Skiing	LW 2	Impairment of one leg (i.e., above-knee amputee)

(*Continued*)

TABLE 8.1 (*Continued*)
Para Sport Classifications for Amputees

Sport	Classification	Description
	LW 4	Impairments in the lower parts of one leg, but with less impact on skiing compared to LW 2; (i.e., amputations above ankle or loss of muscle control in one leg)
	LW 5/7	Impairments in both arms that don't allow for use of ski poles due to a loss of hands
	LW 6	Significant impairment in one arm (i.e., missing arm above the elbow)
	LW 8	Moderate impairments affecting one arm (i.e., below-elbow amputee or cannot flex the elbow or fingers on one side)
	LW 9	Impairment in arms and legs (i.e., amputations affecting one arm and one leg or mild coordination problems in all extremities)
	LW 12	Impairments are similar to LW2-4 but do not have trunk control; eligible to compete either sitting or standing depending on first classification
Boccia	BC 3	Significantly limited function in arms and legs, poor to no trunk control from cerebral or noncerebral origins
	BC 4	Impairments having no cerebral origin, (i.e., muscular dystrophy, spinal cord injuries or amputations affecting all four limbs)
Para Canoeing	KL 3	Have trunk and partial leg function and can use at minimum one leg/prosthesis
Cycling	H5 (handcycle)	Compete in a reclining position; sit on their knees, can use trunk and arms to move the handcycle (i.e., leg amputations, paraplegia or mild to moderate athetosis or ataxia qualify)
	C1 (bicycle)	Most severe activity limitations including coordination impairments, amputations, impaired muscle power or range of motion (i.e., bilateral above knee amputee)
	C2 (bicycle)	Moderate hemiplegic or diplegic spasticity; moderate limb deficiency, moderate athetosis or ataxia, (i.e., unilateral above knee amputee)
	C3 (bicycle)	Eligible if athlete has a bilateral below knee amputation and utilises prosthetics
	C4 (bicycle)	Eligible if the athlete has a unilateral below knee amputation and prosthesis on one leg or bilateral below elbow amputation
	C5 (bicycle)	Least severe activity limitations (i.e., coordination impairments, unilateral arm amputee, impaired muscle power or range of motion)
Equestrian	Grade 3	Severe impairment or deficiency of both upper limbs or a moderate impairment of all four limbs; this classification encompasses short stature as well
	Grade 4	Deficiency of one limb or mild deficiencies of two limbs; also includes vision impaired athletes
Para Ice Hockey (Sled Hockey)	Sport Class 1	Impairment in the lower body that would prevent them from competing in able-bodied ice hockey (i.e., leg amputations, spina bifida, leg length difference of at least 7 cm, etc.)

(*Continued*)

TABLE 8.1 (*Continued*)
Para Sport Classifications for Amputees

Sport	Classification	Description
Para Powerlifting	Sport Class 1	Open to all with any of the eight eligible physical impairment types; impairment in their lower limbs or hips, hindering them from competing in able-bodied weightlifting; all athletes compete in one sport class but in different weight categories (i.e., unilateral/bilateral leg amputees or stiffness of the knee joint)
Para Rowing	TA	Able to use arms and trunk but cannot use the sliding seat when performing strokes (i.e., above/below-knee amputees)
	LTA-PD	Physical impairment but can still use the legs, trunk and arms to move the boat and can use the sliding seat (i.e., those missing three fingers on one hand, or a foot amputation)
Para Shooting	SH1 (pistol)	Upper- and/or lower-limb impairment for pistol events only
	SH1 (rifle)	Lower-limb impairment for rifle events only
	SH2 (rifle)	Rifle-only sport class for those with upper-limb impairments and a need to use a shooting stand for rifle support
	SG-S (trap)	Compete in a wheelchair because of impairment of the lower limbs, but no limitations in the upper limbs
	SG-L (trap)	Compete from a standing position, but have impairment in the lower limbs and no limitations in the upper limbs
	SG-U (trap)	Compete in a standing position, but have impairments in the non-shooting arm
Sitting Volleyball	MD (minimally disabled)	Less severe impairments, and can affect lower and upper limbs (i.e., club foot)
	D (disabled)	More severe impairments, and can affect both upper and lower limbs (i.e., unilateral or bilateral below- or above-knee amputees, congenital deformity/amputation of the upper body)
Para Swimming	S3 SB2	No use of legs or trunk and severe coordination problems from amputations of both arms and legs; athletes with amputations of three limbs
	S4 SB3	Use of arms with hand function, but cannot use trunk or legs; athletes with amputations of three limbs
	S6 SB5	Swimmers with short stature or amputations of both arms, or moderate coordination problems on one side of the body
	S7 SB6	Athletes with one leg or arm on opposite sides or paralysis of one arm and one leg on the same side
	S8 SB7	Amputation of one arm and those with severe limitations across hip, knee and ankle joints
	S9 SB8	Joint restrictions in unilateral or bilateral below-knee amputees
	S10 SB9	Minimal impairments (i.e., the loss of one hand or a movement restriction in one hip joint)
Para Snowboard	SB-LL1	Significant impairments on one or both legs; use of prosthetics during races (i.e., above-knee amputees or combined impairment in two legs, like spasticity)

(*Continued*)

TABLE 8.1 (*Continued*)
Para Sport Classifications for Amputees

Sport	Classification	Description
	SB-LL2	Have an impairment in one or both legs with less activity limitation (i.e., below-knee amputees or mild spasticity)
	SB-UL	Impairments in the upper limbs only
Table Tennis	Sport Class 7	Significant impairments of both legs or the playing arm, or impairments moderately affecting arms and legs (i.e., amputations of both arms above the elbow)
	Sport Class 9	Mild impairments affecting legs or the playing arm; stiff knee or restricted elbow in the playing arm or those with significant impairments in the nonplaying arm
Taekwondo	K41	Unable to block their Hogu (trunk protector) because of loss of upper limbs resulting in decreased kicking power
	K42	Able to block one side of their Hogu; loss or shortening of one arm above the elbow are eligible; others may be able only to cover the upper half of the Hogu on both sides due to shortened arms, and all have a slight reduction in kicking power
	K43	Able to block most of their Hogu, with limited blocking of the lower parts due to a loss or shortening of both arms below the elbow
	K44	Able to block their entire Hogu and have at minimum a loss of one hand through the wrist or an equivalent shortened arm
Para Triathlon These classifications are listed according to the International Triathlon Union (ITU) not the IPC	PTWC	Wheelchair user for daily ambulation: use of recumbent hand cycle on the bike course, and use of racing wheelchair on the run segment; includes those with impairments of muscle power, limb deficiency (i.e., above-knee amputee and spinal cord lesions, severe cerebral palsy)
	PTS2	Severe impairments (i.e., unilateral above-knee amputees, bilateral below-knee amputees, athletes with a significant combined upper- and lower -limb muscle power limitation, severe cerebral palsy, complete brachial plexus, etc.)
	PTS3	Significant impairments (i.e., partial brachial plexus, moderate multiple limb impairments, moderate cerebral palsy)
	PTS4	Moderate impairments (i.e., below-knee amputee, below-elbow amputee, partial loss of muscle power)
	PTS5	Mild impairments (i.e., below-knee amputee, mild cerebral palsy, below-elbow amputee)
Wheelchair Basketball	3.0	Can fully rotate and lean forward, but cannot lean to either side; athletes sit in wheelchairs with low backrest
	4.0	Can move forward and rotate, can only lean to one side due to a leg impairment
	4.5	Mild activity limitation; no restrictions for trunk rotation or leaning forward or sideways (i.e., foot amputations or leg differences of 6 cm are eligible)

(*Continued*)

TABLE 8.1 (*Continued*)
Para Sport Classifications for Amputees

Sport	Classification	Description
Wheelchair Fencing	Category A	Good trunk control allowing the athlete to move forward and sideways in a fast manner; fencing arm is fully functioning (i.e., lower-limb deficiencies and paraplegia)
	Category B	Impairments impacting the legs and trunk or the fencing arm (i.e., an athlete with incomplete tetraplegia)
Wheelchair Rugby	3.5	Good arm and hand function, and some trunk function present (i.e., bilateral below/above-knee amputees with loss of fingers or hand impairment on both sides of the body)
Wheelchair Tennis	Open Class	Permanent and significant impairments of one or both legs with normal arm function (i.e., paraplegia or leg amputees)
	Quad Class	Impairments affecting both playing arm and legs

In running, prosthetics are commonly used. In fact, to be discussed in more depth later in the chapter, prostheses for below-knee amputees are so well designed for ground reaction rebound ability and fit so well that the Para athlete can adopt a near-normal running cadence, which is fuelling the current debate of whether these devices put able-bodied athletes at a disadvantage. For athletes with above-knee amputations, running becomes more challenging, with the stride more like a hop-skip type pattern, due to the prolonged swing phase of the prosthetic limb (Bragaru et al. 2011). Interestingly, some athletes with an amputation choose not to use a prosthetic limb, preferring to use crutches instead, possibly due to pain experienced with their prosthesis or improved speed and fluidity of movement.

COMMENTARY BOX 8.2

Diana's Story

A famous American skiing amputee, Diana Golden-Brosnihan, completed both her dry land and on-snow training and competitions without a prosthesis. A Gold Medallist at the Calgary 1988 Paralympics, she used one ski and two outriggers (forearm crutches with ski tips attached) in her initial years as a skier. In later years, she abandoned the outriggers in favour of regular ski poles so she could go faster. Diana never used a prosthetic leg and became well known for running with crutches. In fact, Diana ran up the mountains during a training camp in Austria alongside able-bodied athletes (unpublished observation, N. Meyer). Diana was inducted into the Women's Sports Foundation International Hall of Fame and the National Ski Hall of Fame in 1997 (Litsky 2001).

8.2.1 Medical Issues in Athletes with an Amputation

While athletes with amputations may not show compromised physiological responses to exercise, there are other issues related to the degree of the missing body part that athletes with an amputation manage daily. From a nutritional perspective, energy expenditure may be increased due to the inefficiency of movement, with or without fitted prostheses.

It is common for athletes with an amputation to be naturally asymmetric. Swimmers, for example, have difficulty maintaining balance, thus oscillating more frequently with a less effective streamline position, which may increase energy expenditure and decrease performance capacity compared with able-bodied athletes (Bragaru et al. 2011). Asymmetric movements may disrupt the kinetic chain and compensatory strategies may also overload other areas or links, increasing the risk of injury (Rice et al. 2011). In addition, athletes with an amputation can suffer from pressure sores and subsequent infection at the site where the prosthetic and stump of the amputation intersect, requiring immune-modulating nutritional strategies to be incorporated.

Finally, depending on the sport, training environment and physical discomfort, athletes with an amputation may be at risk of dehydration due to restrictions in being able to handle fluid such as an athlete using two crutches during the run segment of a triathlon, or limited access to bathroom facilities for a sit-skier.

8.2.2 Common Injuries in Athletes with an Amputation

In general, athletes with an amputation are not at greater risk for injury compared to their able-bodied counterparts. However, injuries more commonly seen in athletes with an amputation include:

1. Injuries to the skin and spine
2. Injuries related to overuse of certain parts of the body such as the shoulders, wrists, knees, elbows
3. Poor bone health due to inadequate loading of the affected side compared to the sound leg and/or simply the result of spending less time doing weight-bearing activity.

Ambulating athletes with an impairment (across all classes) are more likely to suffer injuries to the lower extremities than the upper extremities (Ferrara and Peterson 2000). However, upper extremity overuse injuries are common in sports in which amputees are not able to use their prosthetics. Ambulating amputees are also more likely to suffer lower-extremity injuries than those who use a wheelchair for daily mobilisation (Ferrara and Peterson 2000). Coaching athletes with an impairment requires the use of comprehensive training strategies to help decrease injury risk. Training load should be monitored and may include the addition of training sessions outside of the respective sport to help minimise impact on the residual limb, increase recovery time and minimise injury.

COMMENTARY BOX 8.3

COACH'S INSIGHT: What are the biggest differences in coaching athletes with an impairment compared to able-bodied athletes?

> Athletes with an amputation cannot undertake as much vertical loading as other track athletes due to the impact on their stump. Therefore, you have to incorporate more water running/pool sessions.

Iryna Dvoskina, Athletics coach of multiple Paralympic medallists.

8.2.2.1 Skin Injuries

Pressure sores and infection risk are high in athletes with an amputation who ambulate either using prosthetics or for those using wheelchairs. Stump injuries are frequent and include skin abrasions, pressure sores, blisters and rashes due to interaction with an improperly fitted prosthetic or from too much movement between the prosthesis and the stump, especially during times of high heat and humidity when sweat rates increase. Keeping the stump clean with appropriate skin care, particularly after sweating, can decrease the prevalence of abrasions and sores. If problems arise, nutritional approaches such as increasing consumption of sufficient calories and protein, foods rich in vitamin C (e.g., citrus fruit, berries, bell peppers, broccoli), fish oils (e.g., salmon, mackerel) and zinc (e.g., lean beef, yogurt, beans, fortified cereal) can encourage wound healing. Zinc supplementation may expedite healing; however, careful consideration for the duration of supplementation needs to be monitored as excess zinc interferes with iron and copper absorption and may negatively impact performance. Refer to Chapter 12 for further information concerning wound healing.

8.2.2.2 Compensatory-Related Injuries

The improper fit of prostheses can result in lower coordination of muscle groups and increased susceptibility of sport-related muscle pain. Back injuries are also common with upper-extremity amputations and occur predominantly at the cervical and thoracic spine. These injuries are attributed to imbalance, unequal movements and compensatory strategies of limbs during physical activity or daily walking. On the other hand, lower-limb amputations are also associated with low back pain due to excessive lumbar spine lateral flexion, extension and rotation at the trunk as a compensatory mechanism. For example, an athlete who is walking forward may prefer to twist their neck or back to look to the side or behind them to avoid taking extra steps or changing directions quickly while ambulating with prosthetics. Particular attention should be focused on core and back strengthening and flexibility to alleviate these problems.

8.2.2.3 Overuse Injuries

Injuries to the intact limb are often the result of overuse injuries such as stress fractures and tendonitis of the wrist, elbow, shoulder, patella and Achilles. Medical databases reviewed from the 2012 London Paralympic Games showed chronic overuse injuries accounted for 31.8% of all reported injuries during the Games (Willick et al. 2013). These are common injuries sustained by athletes with an amputation due to the confines of their sport or as a result of ambulating/transporting without their prosthetics. Repeated assessment of running and walking gaits may help prevent some of these overuse injuries (Klenck and Gebke 2007). Shoulder-related injuries (impingements and inflammation) along with elbow and wrist tendonitis are commonly seen in sled hockey, Nordic skiing and sitting volleyball athletes due to over use of the upper body and the pushing requirements of their sport. Patellar tendonitis is common in lower-body unilateral leg amputees from hopping around on their sound leg when moving around without their prosthetic. This is often seen in sled hockey athletes when transferring out of the sled and back into the prosthetic, which is typically stored in the locker room, and may be a substantial distance from the ice.

8.2.2.4 Bone Mineral Density in Amputees

Low bone mineral density (BMD) and risk of bone injury are higher in athletes with lower-limb amputations due to lower ground reaction forces and muscular loads (Scaramella et al. 2018). Amputation level has been seen to influence bone characteristics, with above-knee amputees having greater bone atrophy than below-knee amputees, leading to greater risk of osteoporosis and fractures in the hip (Sherk et al. 2008). Furthermore, greater reductions in BMD may occur after traumatic amputations, as compared with nontraumatic amputations (Leclercq et al. 2003). Athletes with amputations may therefore be at higher risk of sustaining osteoporotic fractures at a younger age compared to able-bodied counterparts. However, amputees who wore a prosthesis for more than 6 hours per day had significantly greater hip BMD than those who wore a prosthesis for less than 6 hours per day (Leclercq et al. 2003).

Bone mass in unilateral below-knee amputees differs between impaired and intact limbs. Intact proximal tibia BMD has been reported to be 45% greater than the impaired side (Royer and Koenig 2005). A possible explanation for this difference is the increased load on the knee compartment of the intact limb. Despite the increase in BMD, the intact limb of unilateral below-knee amputees is susceptible to irreversible degeneration and osteoarthritis due to repeated stress on the joint (Royer and Koenig 2005). Melzer et al. (2001) found some degree of knee osteoarthritis in 65.6% of unilateral, lower-extremity amputees, which was significantly higher than in able-bodied controls. Knee injuries consisted of patellar and medial osteophytosis. Osteoarthritis is not dependent on BMD but is a multifactorial disease impacted by age, body mass, joint injury and genetic factors (Royer and Koenig 2005).

Risk factors of low BMD in amputees (adapted from Scaramella et al. 2018):

- Level of amputation, with a greater risk in above knee than below knee
- Prosthesis fit
- Insufficient weight bearing on residual limb
- <6 h/d spent on prosthesis
- Compensatory loading on intact limb

Assessing vitamin D status in athletes with an amputation is recommended not only to achieve optimal levels for sport performance and immune function, but to help mitigate any further risk of declining BMD. Additionally, routine assessment of BMD using dual-energy x-ray absorptiometry, plus assessment of parathyroid hormone and dietary calcium intake, are important to help detect further risk factors for suboptimal bone health in this population (Scaramella et al. 2018). Encouraging intake of calcium-rich foods such as dairy products, fish with edible bones, tofu, dark leafy greens and calcium-fortified foods is warranted. See Chapter 12 for more information on optimising vitamin D status in Para athletes.

In summary, athletes with an amputation are not expected to suffer from greater injuries due to sport participation than their able-bodied counterparts. However, there may be long-term effects on bone, muscle and connective tissue in amputees because of asymmetry and overuse, leading to acute sport-related muscle pain as well as osteoarthritis and early onset of poor BMD compared to able-bodied athletes. Prevention of these injuries includes:

- Careful fitting of prosthetics
- Maintenance of body mass and composition
- Assessment of BMD, vitamin D status and calcium intake
- Adequate time spent doing weight-bearing activity
- Properly periodised training and competition plans supported by performance-based fuelling strategies

Furthermore, amputees engaging in sports with minimal weight-bearing activity (i.e., swimming, cycling and triathlon) should consider increasing other weight-bearing activities such as resistance training to help mitigate these effects.

8.3 ENERGY EXPENDITURE IN ATHLETES WITH AN AMPUTATION

The assessment and analysis of components of energy expenditure used for able-bodied athletes may not be consistently applicable to athletes with an amputation (Van de Vliet et al. 2011). Resting metabolic rate (RMR) is often estimated using prediction equations; however, these cannot be applied to athletes with an amputation unless the amputation is of small magnitude or adjustments are made for the missing limb. In fact, estimating RMR using formulas in amputees will overestimate by

5–32% (Buchholz and Pencharz 2004). In addition, prediction equations often require the determination of height and body mass. For a lower-limb amputee, height assessment may be challenging due to the possible inability of the athlete to stand upright or not being a measure of true height if they are a bilateral amputee. Other methods of measuring height, such as supine or sitting height, may be applied in this population and considered within their own limitations. As outlined in Chapter 3, the Cunningham equation (1980) is often used to estimate RMR, but it requires lean body mass from body composition assessment, which relies on there being a validated method of measuring lean body mass (refer to Chapter 13). Juzwiak et al. (2016) found the Cunningham equation to overestimate RMR and Owen's equation to be the best predictive equation of RMR in track and field athletes with a limited limb deficiency when comparing different equations with indirect calorimetry. In contrast, Howell et al. (2015) found that the Owen, Mifflin St. Jeor and Harris-Benedict equations (see Table 3.1) tended to underestimate RMR in healthy military service members with more significant lower limb loss. Howell et al. (2015) did find the 25 kcal/kg body weight predictive factor to be the most consistent measure of RMR compared to indirect calorimetry.

Osterkamp (1995) reviewed body proportions for the determination of energy requirements of subjects with amputations. In a total of 21 subjects, Dempster (1955) and Clauser et al. (1969) reported the following body proportional values: 8% head, 50% trunk, 5% total arm (1.6% forearm, 2.7% upper arm, 0.7% hand) and 16% total leg (10.1% thigh, 4.4% calf, 1.5% foot). These body proportions may be used for adjustments of RMR in amputees; however, there are currently no data to validate this in an athlete population.

Other components of total daily energy expenditure (TDEE) of relevance to athletes are non-exercise adaptive thermogenesis (NEAT) and energy expenditure of exercise (EEE), both having a great potential to increase TDEE. Currently, there are no published metabolic equivalents (MET) for amputees that could help estimate energy expenditure during daily activities and, most importantly, during exercise. The current literature, although limited, provides some insight into the differences in energy expenditure. In a study comparing energy cost of walking and running between above-knee amputees and able-bodied runners, VO_2 during walking was significantly increased by 45–78% for above-knee amputees, and gait economy was decreased compared to non-amputee controls (Mengelkoch et al. 2017). During running, VO_2 was 29–34% greater for above-knee amputees compared to non-amputee controls (Mengelkoch et al. 2017). Research investigating oxygen consumption (VO_2) during exercise in amputees shows greater oxygen uptake (VO_2) for proximal versus distal leg amputations. Schmalz et al. (2002) showed that the VO_2 for treadmill or free walking is about 25% higher in below-knee amputees using a prosthesis, while above-knee amputees using a prosthesis exhibited a remarkable 55–65% increase in VO_2 during exercise compared with able-bodied counterparts. Thus, the more proximal the amputation, the greater the tissue loss and the higher the EEE during movement. Concurrently, RMR is expected to be lower the more proximal the amputation; therefore, total daily energy expenditure may not be different from an able-bodied counterpart, depending on the volume of exercise undertaken. Interestingly, it is not only the location of the amputation that determines energy expenditure, but data suggest a direct link between the cause of the amputation (e.g., peripheral vascular disease and diabetes versus traumatic injury or congenital causes) and energy expenditure, with disease-related removal of limbs creating a 20–35% increase in energy expenditure (Schmalz et al. 2002) most likely due to pre-existing health, mobility and fitness status.

Applying this information, it appears that the best practise strategies to estimate EEE and TDEE in an athlete with an amputation may include measuring RMR or estimating RMR using prediction equations that either use LBM or are proportionally adjusted, such as the Cunningham equation or 25 kcal/kg. For EEE, there is no doubt that measuring VO_2 during exercise would provide a more valid assessment. Portable indirect calorimetry devices are available and future research should attempt to measure VO_2 in athletes with various degrees of amputations participating in different sports in order to present a representative range. If indirect calorimetry is not available, portable devices such as heart rate monitors and accelerometers may be valid in ambulating athletes with an amputation, but cross-validation with VO_2 would still be required. Finally, the Compendium for Physical Activities (Ainsworth et al. 2011) could also be used for both ambulating activities and general and sport-specific training, particularly arm amputees. Adjustments, as identified by Schmalz et al. (2002) for BKA (25%) and AKA (~60%), are needed to account for inefficiency of movement in certain, but possibly not all, activities.

When assessing and calculating energy expenditure in athletes with an amputation, careful consideration must be taken to educate athletes and staff on the performance and health consequences of low energy availability (LEA). Athletes who carefully monitor their body composition and body weight are at higher risk of LEA, and some athletes may intentionally restrict their energy intake, fearing that excessive weight change may alter the fit of prosthetics. Due to the higher risk of low BMD in amputees, these athletes may worsen their low BMD by being in LEA and increase their risk for sports-related illness and injury compared to their able-bodied peers (see Chapter 4 for more detail).

8.3.1 Do Prostheses Offer an Advantage to Athletes with an Amputation?

Advances in prosthetic technology have resulted in dramatic improvements of energy-storing properties of the prosthesis. This may alter the efficiency of a lower-limb amputee's gait, potentially diminishing the higher energy demands placed on the athlete. Significant metabolic differences appear nonexistent at normal walking speeds among below-knee amputees using prosthetics with various foot designs and carbon fibre springs. Increased energy efficiency is noted at speeds at or above 4.8 km/h, transitioning from walking to running (Schmalz et al. 2002). However, the placement and alignment of the prosthesis is critical. Schmalz et al. (2002) found that a small (i.e., 2 cm) anterior shift of the single axis knee joint significantly increased energy expenditure by 13%, attributed to the increased demand on the hip extensors to prevent prosthetic knee collapse. Thus, if not aligned optimally, a prosthesis can be more energy inefficient and may also lead to compensatory strategies that may result in overload of other areas and potential injury.

To date, running with prosthetics continues to offer no overall performance advantage to amputees over able-bodied athletes. Nolan (2008) investigated the metabolic cost of a carbon fibre prosthesis versus a prosthesis not specifically designed for running among bilateral and unilateral amputee and able-bodied counterparts. Use of a carbon fibre prosthetic made for running resulted in lower heart rates and VO_2 compared to running with a prosthesis not designed for running. Interestingly, VO_2, heart rate and VO_{2peak} between able-bodied individuals and amputees using the carbon fibre prosthesis were not different. The authors concluded that the use of carbon fibre prostheses would allow an amputee to reach equal but not greater running economy than able-bodied counterparts. Weyand et al. (2009) investigated the metabolic cost and mechanics during constant speed treadmill running in a bilateral, BKA sprinter versus competitive male runners with intact limbs. The amputee sprinter exhibited a metabolic cost 3.8% lower than able-bodied elite distance runners, 6.7% lower than subelite able-bodied distance runners and 17% lower than able-bodied 400-m sprinters. Physiologically, relative sprinting endurance during all-out speed trials was almost identical between the amputee and able-bodied runners. However, at higher speeds, running mechanics differed between the amputee and able-bodied athletes. In running amputees, especially sprinters using advanced technology prosthetics, it can be assumed that EEE is similar to that of able-bodied athletes. This should, however, not be assumed in other athletes with an amputation, as it is likely that TDEE is higher due to both increases in NEAT and EEE (Meyer and Marshall 2014). Sport nutrition professionals and physiologists working with athletes with an amputation should carefully assess each individual athlete's degree and location of amputation and prosthetic devices used in both daily living and/or sport in order to accurately quantify energy needs. Measuring VO_2 under resting, ambulating and various exercising conditions is likely the most accurate assessment of individual needs.

Research and new developments of prostheses have advanced while technology continues to aim at improving the options for amputees. Throughout 2011/2012, there was substantial international attention regarding whether artificial legs can prove advantageous among athletes with amputations, and whether this puts able-bodied athletes at a disadvantage if competing in the same race. Since 2012, the debate over whether prosthetic legs provide a competitive edge over able-bodied athletes has slowed. It is becoming more accepted that bilateral amputees with running legs are at no additional advantage when competing against able-bodied runners. Unilateral amputees are likely disadvantaged (at least over distances longer than 100 m), as they do not have the same running gait or efficiency as bilateral amputees or able-bodied runners due to compensatory patterns of running biomechanics using one prosthetic. Additionally, there are now updated processes during track and field classification where a maximum height limit is set to avoid issues of disproportionality in the length of prosthetic limbs leading to a distinct performance advantage (Figure 8.1).

FIGURE 8.1 Photograph of bilateral BKA (Nick Rogers, USA) in running prostheses approved for his maximal height allowance. (Photo courtesy of Liz Broad.)

8.4 SPECIFIC NUTRITION CONSIDERATIONS IN ATHLETES WITH AN AMPUTATION

The Paralympic movement is growing, with more athletes, including amputees, competing at international games, yet very little is known about these athletes' specific nutrition needs. Silva Gomes et al. (2006) assessed anthropometrics and nutritional intake of the Brazilian Amputee Men's Soccer Team. Twelve of 13 field players had above-knee amputations, while the thirteenth had a below-knee amputation. Eleven amputations were caused by trauma, one was congenital and the last was attributed to complications of cancer. Using a 6-day dietary record, mean daily energy intake was 16,086 ± 4368 kJ/d (3830 ± 1040 kcal/d), protein intake was 203.8 ± 53.1 g/day (3.1 ± 0.8 g/kg/d), carbohydrate intake was 482.4 ± 131 g/day (7.3 ± 2.1 g/kg/d) and fat intake was 29% of total energy intake. From these data, it appears that the average carbohydrate intake in Brazilian amputee soccer athletes was sufficient at 6–10 g/kg/d body mass, which meets recommended carbohydrate needs (see

Chapter 3). Goalkeepers showed the highest intake of fat and lowest of carbohydrate, while midfielders and forwards had higher carbohydrate intake. Considering the high carbohydrate needs of team sport athletes (Holway and Spriet 2011), sport nutrition professionals need to individualise carbohydrate recommendations, especially in athletes with an amputation playing in various positions. Unfortunately, this study did not report any data on training volume and/or intensity; thus, this data is difficult to put into the context of energy balance or availability.

Para athletes of all impairment types are at risk of inadequate dietary intakes to support athletic performance (Scaramella et al. 2018). Limited nutrition education and lack of knowledge regarding how to balance dietary intake to meet recommended daily allowances (RDAs) are likely two of several reasons responsible for nutrient deficiencies in Para athletes (Rastmanesh et al. 2007). Inadequate energy intakes and the nature of an athlete's impairment may put the athlete at greater risk for micronutrient deficiencies and lead to negative effects on performance. Bilateral leg amputees may be at risk for macro- and micronutrient deficiencies due to reduced metabolic rates and lower energy expenditure at rest and depending on ambulation mechanics compared to unilateral amputees or able-bodied athletes, resulting in a reduction in overall calorie intake (Scaramella et al. 2018).

While there is limited research related to nutrition in athletes with an amputation, Scaramella et al. (2018) discussed common nutritional issues in non–wheelchair using athletes such as amputees:

- Increased energy needs due to inefficiency of movement when ambulating (see Section 8.3)
- Reduced metabolic rate and overall energy expenditure in double-leg amputees (see Section 8.3)
- Heightened risk for discomfort, pressure sores and infection at contact site between prosthetics and amputation
- Abnormal sweat rates and poor thermoregulation due to a reduced ability to dissipate heat, resulting in potential difficulty adjusting to competing in hot climates
- Possible problems with digestion and associated bowel movements as well as hydration and urination

8.4.1 Carbohydrate and Fuelling

Most athletes with an amputation can follow general fuelling guidelines for before, during and after exercise as outlined in Chapter 3. Adequate carbohydrate intake is necessary to maintain training intensity, combat fatigue, protect immune function and support training adaptations. Bilateral leg amputees with substantially less active muscle mass proportional to their body weight should use the lower end of the range for recommended carbohydrate intakes presented in Chapter 3. Increased energy needs due to inefficiency of movement of ambulant athletes with lower-limb amputations may increase glycogen use and therefore carbohydrate needs. In able-bodied athletes, adequate stores of muscle glycogen are reported to sustain approximately 90–120 minutes of continuous moderate to high-intensity exercise

(Jeukendrup et al. 2015). In contrast, although no evidence has been published on the muscle glycogen storage capacities of Para athletes, experience suggests those using smaller muscle groups like bilateral leg amputees are able to sustain approximately 75–90 minutes of continuous moderate- to high-intensity exercise (Scaramella et al. 2018). Therefore, attention must be paid to ensuring athletes with an amputation are educated in adequate fuelling and during exercise carbohydrate intakes to support moderate- to high-intensity training and optimal power output during competitions lasting 75 minutes or longer.

8.4.2 Protein and Recovery

While no published data exists on the protein needs for athletes with an amputation, they are likely similar to able-bodied athletes. Recommended protein intake should be based on body weight measured without a prosthetic on. Athletes with an amputation should adopt similar recovery nutrition strategies as able-bodied athletes, as outlined in Chapter 3.

COMMENTARY BOX 8.4

EXPERT COMMENTARY: Protein requirements in amputee athletes (Dr Luc van Loon, Maastricht University, and Prof Kevin Tipton, Stirling University)

Question: Do you believe the protein requirements for optimising muscle protein synthesis (i.e., 20–25 g post exercise) are the same in athletes in amputees (especially bilateral leg amputees) compared to able-bodied individuals?

Answer: Quite possibly the protein requirements are very similar, despite their reduced absolute amount of active muscle tissue. A lot of the protein ingested is used in the gut, and this component is unlikely to change. Unlike carbohydrate requirements, it doesn't appear as though (minimal) protein requirements can be advised on a "per kg body mass" basis directly. Therefore, if requirements are different, it's likely that differences are small (i.e., 5 g lower).

8.4.3 Hydration and Cooling

Amputees may be at greater risk compared to their able-bodied counterparts for dehydration, overheating, muscle cramps and experiencing heat exhaustion and heat stroke (Scaramella et al. 2018). Athletes with an amputation have less skin surface area to dissipate heat and therefore may be at increased risk of higher core temperatures. Impaired thermoregulation may slow acclimatisation in hot and humid environments (Van de Vliet et al. 2011). Assessing athletes' individual hydration status, using urine-specific gravity and urine colour charts prior to exercise and estimating sweat rates during exercise are necessary to implement individualised fluid replacement and hydration guidelines, as outlined in Chapter 5.

Bilateral leg amputees may experience more issues with thermoregulation and heat acclimation compared to unilateral amputees. Some amputee athletes participating in sports requiring personal protective equipment (i.e., sled hockey) may voluntarily choose to wear less padding to help keep themselves cooler, putting them at greater risk for sustaining injuries. Careful attention should be paid to educating amputee athletes on adequate hydration and cooling strategies to meet their increased needs, especially in hot environments or in sports with personal protective equipment. Cooling strategies should be used to help improve thermoregulation and cooling core temperatures. See Chapter 5 for more information.

Athletes who use a wheelchair for transportation may need special attention and customising, especially targeting fluid replacement strategies before and after exercise. Sodium aids in fluid retention (Shirreffs and Sawka 2011) and may be used before and after exercise as an effective replenishment and rehydration strategy. Adding salt to both fluids (i.e., soup broths, smoothies, sport drinks) and meals, especially in athletes training and competing in hot conditions or in environmental conditions where restroom access is both limited and burdensome, can help restore fluid losses and effectively rehydrate.

When working with athletes with an amputation, it is imperative to assess each athlete thoroughly in order to develop an individual hydration and cooling plan targeting the unique issues of each athlete based on their background, level of impairment and training demands.

8.4.4 Nutritional Interviews with Paralympic Amputees

Due to the scarcity of data on nutrition in athletes with an amputation, nutrition considerations for this chapter will be summarised based on interviews with six successful Paralympic athletes.

Athlete 1 is a male alpine sit skier with a bilateral above-knee amputation and born with lumbar sacral agenesis, a genetic disorder resulting in no lumbar vertebrae or sacrum. The muscles in his legs did not develop and were amputated at age 4. He uses a wheelchair for transportation rather than ambulating with prosthetics like the other five athletes interviewed.

Athlete 2 is a female sitting volleyball athlete with a unilateral below-knee amputation from a congenital birth defect, fibular hemimelia. She was 2 years old when her parents decided to amputate her foot.

Athlete 3 is also a female sitting volleyball athlete with a unilateral below-knee amputation caused by a traumatic boating accident at 21 years of age.

Athlete 4 is a Para triathlete with a unilateral above-knee amputation, the result of osteosarcoma diagnosed at the age of 12. She lost the majority of her left leg at age 14.

Athlete 5 is also a female Para triathlete and army veteran with a unilateral above-knee amputation caused by a military-related service trauma in 2004 while serving in Iraq.

Athlete 6 is a male sled hockey player with a bilateral above-knee amputation from a congenital birth defect called tibial hemimelia, whose tibias and other foot bones were amputated at 10 months old.

Each of these individuals reported differing views of sport nutrition and managing their impairment. Some have more soft tissue, muscle or bone remaining in their residual limb compared to others. While there are overlapping nutritional challenges, it is important that coaches, sport nutrition professionals and other performance staff working with these individuals understand the unique characteristics of the athlete they are supporting. Challenges facing these athletes include training demands, maintaining body weight, combating overall health concerns and managing activities of daily living.

8.4.4.1 Body Composition and Maintaining Prosthesis Fit

Nutritional issues addressing body mass/composition management included portion control, hydration and sodium intake. While minor adjustments by a prosthetist can occur more frequently, new prosthetic fittings take place once every 1–2 years in the United States, depending on health insurance. It is important to maintain weight to ensure proper fit of the residual limb into the socket of prosthetics. In addition, increased sodium intake, heat or travel can cause these athletes' limbs and/or thighs to swell, making their prosthetic fit extremely uncomfortable. A frequent outcome of a misaligned prosthesis fit is the development of pressure sores, wounds and infection, which may take weeks to heal and require time out of training.

Athlete 1 reported portion size and weight management along with hydration as daily challenges. While operating his wheelchair and his sit ski, almost 100% of his body weight is resting on his stomach, creating a constant feeling of fullness. To relieve this "full" sensation, the athlete must hold himself up on the armrests of his chair. Through a collaborative effort with a sport nutrition professional, this athlete has found strategies to meet his nutrition needs while limiting gastrointestinal discomfort during training and racing.

Three out of the five athletes interviewed who ambulate with prosthetics expressed a need to maintain weight within about a 5–10% range of current body weight to ensure their prosthetics fit comfortably for ambulation and during training and maintenance of daily routines. Their main nutritional concerns are maintaining weight through energy balance and monitoring sodium intake. If too much weight is lost or gained, or excess sodium is consumed, liners are removed or added to help create more room or fill in any gaps to avoid sores from an improper fit, which can cause time away from training and avoidance of ambulation.

Athlete 4 reported summer being a time when she struggles the most with the change in how her residual leg fits into the socket of her prosthetic. Summer time is the peak of triathlon racing season. She typically losses volume at the distal end of her leg due to the increased training volume, and the socket becomes too big for the residual leg. In contrast, the off-season presents the opposite challenge and she typically visits with her prosthetist to have her socket slightly enlarged to account for a reduction in training and a change in body composition. Athlete 2 stated that when body weight is outside of her normal range, she notices her leg "falls asleep" or feels suffocated. She also reported when she has decreased her body composition significantly for performance, her prosthetic digs into the back of her knee and hamstring, creating sores. Additional socks are used to accommodate gaps, but the fit is still not as comfortable. Athlete 6 reported increases in pain from his prosthetics due to swelling caused by excess sodium intake or weight gain. When this occurs, he avoids putting his prosthetics back on and tends to walk around on the ends of his residual limbs, putting him at risk for bone spurs. He also mentioned using a chair to bring him up to counter height in order to prepare meals when his prosthetics are ill-fitting and causing too much discomfort to put back on for ambulation. He reported a decrease in motivation to train when his prosthetics were not fitting properly.

8.4.4.2 Travel

The majority of athletes interviewed discussed nutrition challenges in regards to travel, especially long-haul travel as limbs swell. These athletes expressed the importance and effort they put into staying hydrated while travelling and avoiding too much salt or salty foods to avoid furthering any issues in the swelling of their residual limb(s). Most athletes reported removing their prosthetic(s) during any travel >2 hours in duration for comfort, while focusing on hydration or using compression sleeves also known as "shrinkers" to help control swelling. This also helps avoid problems with prosthetic fit when putting prosthetics back on to move about the cabin, use the bathroom, or upon arrival at their final destination. Athlete 2 explained that leaving her prosthetic leg on for long-duration flights irritates her skin because the liner does not allow her skin to breathe. Removing her prosthetic during long-haul travel not only helps with comfort, but also prevents skin injuries.

8.4.4.3 Hydration and Thermoregulation

Maintaining adequate hydration is a challenge for Athlete 1. His body weight not only rests on his stomach but also on his bladder. When strapped into his sit ski while training and racing on the mountain, it is extremely inconvenient for him to use the bathroom. Unlike other skiers with an impairment, he cannot use a leg bag for urine collection due to limited space in his bucket. Although he knows it may be detrimental to his performance, he will purposefully dehydrate the day of practise or on race day. He reports that the alternative to competing dehydrated is not worth the consequences or discomfort of an accident. Whereas the typical approach would be to find a strategy for this athlete to maintain euhydration during skiing, it is critical to individualise sport nutrition approaches, even if they may not align with current recommendations. If athletes purposefully refrain from drinking to avoid discomfort and lengthy bathroom breaks, they may risk dehydration and urinary tract infection (UTI). Pre-hydration and vigorous fluid replacement after exercise are key to ensuring timely recovery. Recommendations for this athlete include taking a daily probiotic and consuming cranberries or cranberry tablets to decrease the risk of a UTI and/or some electrolytes to promote the uptake and absorption of the fluid he consumes. This is probably a better strategy than forcing him to change his hydration routine on the mountain. Cranberry-containing preparations (e.g., juice, concentrate, tablets) may assist through antimicrobial and antibacterial properties, although a recent review does not suggest cranberry preparations to be effective in preventing UTIs in all individuals (Pannek and Wollner 2017).

Prosthetic fit can be influenced by nutritional factors such as hydration. Gailey and Harsch (2009) suggested that the body fluids lost during long-distance cycling and running can reduce residual limb volume of amputees, resulting in excessive movement of the limb in the prosthetic socket. Attenuating fluid loss during exercise and adopting effective fluid replacement strategies after exercise may be extremely important in this population of athletes. Amputees exhibit substantial sweat loss on their residual limb from extended time spent walking or after running, as prosthetics and liners are quite insulated and impermeable to moisture. This sweat loss is amplified on hot and humid days. Prosthetics and liners need to be removed and wiped down after sweat collects in order to reestablish proper fit. Athlete 5 discussed the constant battle with sweat and removing sweat on her residual limb. She reported an increase of residual limb sweat losses on hot days or in hot environments. After a long run, or even just walking around, she described having to remove her walking or running leg and wipe her residual limb off in order for her prosthetic to fit correctly again. While the technology is improving, most amputees do not possess prosthetics with ventilation. Athlete 5 stated she also saw a difference in thermoregulation post-injury. She notices others often get cold before she does. Athlete 4 mentioned the chafing she experiences at the trim line where the socket hits while running in hot and humid conditions because of limited ventilation in her prosthetic. The increased sweat rate causes her prosthetic to move around quite a bit.

Bilateral amputees and those with significant limb loss may have higher core temperatures due to less skin surface area making it more difficult to dissipate heat and cool the body efficiently. Unlike athletes with a spinal cord injury, amputees have the capacity to increase sweat rate as a consequence of an increased core temperature. This increases fluid and electrolyte needs, especially in hot climates (i.e., triathletes, cyclists, track runners) or when wearing protective equipment (i.e., sled hockey). Athlete 6 is aware of his increased hydration needs and over time has realised the need to increase his fluid intake to match his sweat losses, especially after training and games while wearing protective pads. Cooling strategies as described in Chapter 5 are also important for this athlete to bring his elevated core temperature down after exercise or between breaks in activity (i.e., period intermissions).

Athlete 2 reported water and salt being two main factors she focuses on for maintaining her daily comfort. The morning after eating a salty meal, her prosthetic leg feels quite snug in the morning and sometimes uncomfortable. If she had training, this may even cause bleeding through her callus at the bottom of her residual limb. When she was younger, she was not aware of what was causing the swelling the next morning and did not know how to control it, but as her nutrition education increased so did her awareness and ability to relieve the discomfort by removing socks. Athlete 3 stated she avoids fried foods and high-sodium meals (unless needed after training to replace electrolytes) to minimise issues of swelling in her residual limb.

8.4.4.4 Future Health Concerns

Daily barriers faced by athletes with amputations are unique to each individual athlete. Athlete 1 expressed quite different challenges than did the other ambulating athletes. The wheelchair-bound athlete described challenges related to housing layout and accessibility to public places as daily barriers. The heights of countertops in most apartments are not conducive to access by an individual in a wheelchair. If this athlete wants to unload the dishwasher, he must first unload the dishes onto the countertop, then climb on the counter and put them away a second time into the cupboards. He also expressed difficulties with narrow kitchens; if the refrigerator door opens the wrong way, it is impossible to get his wheelchair around to get into it. This athlete will ambulate on his hands while at home to overcome these obstacles. Difficulty accessing food may hinder this athlete from fuelling properly on training days. Travelling to competitions has exposed this skier to many cultures. Some social groups give him a sense of disapproval toward his impairment but are amazed by his resourcefulness. He says people often just stare, however those who do attempt to help are often overzealous. This athlete says, "You can't be anonymous. You can't just go to the grocery store. I'm either going to be stared at or be such an amazing inspiration to a group of people." He shows his frustration toward the stigma associated with his impairment.

Athlete 6 with the bilateral above-knee amputation described ambulating to be quite energy depleting. The amount of energy required to walk is physically draining, as it requires more energy compared to an able-bodied athlete. Furthermore, if his prosthetics are left in a cold ice hockey rink locker room while he is training or competing, it often takes a while for the mechanical components of his knees to warm up and bend properly. Mobility and walking are a bit more unstable at this time, and this is exacerbated during winter months when ice on the ground puts him and other amputees at increased risk for slipping and injuring themselves. Athlete 5 stated that winter months with ice and snow force her to move her running inside to avoid injury from a slip. She mentioned wearing cleats on the bottoms of her shoes to help grip the snow and ice better to prevent slipping or falling. During the 2018 Winter Paralympic Games in PyeongChang, when the snowfall increased or ground conditions included too much ice and risk for injury, transportation vehicles to competition venues needed to be brought closer to athlete lodging in the Paralympic Village to avoid slips and falls. Daily challenges faced by athletes with an amputation include weather related obstacles (i.e., slippery ice) and walking on different textured floors. For example, hardwood and tile floors are typically easier to navigate than floors covered with rugs. Transitioning from one surface to another also poses a challenge, especially in bilateral amputees. Besides the physical act of walking, stopping presents another difficulty; it is almost impossible for some athletes to stop short if someone ahead of them stops quickly or intersects their path. Despite the challenges faced, many athletes with an amputation do not consider themselves impaired. As one athlete says, "This is part of me. You don't leave the house without your keys or cell phone. I don't leave the house without my legs. I don't think of myself as impaired. I do have legs. I just put them on. There's not anything I can't do."

The current training/competition routines in which these athletes engage can put them at risk for greater health complications later in life such as hip and knee replacements, back problems and arthritis. The amount of force placed on their joints without adequate support, from either another leg or joint, can be overwhelming. Educating athletes on nutrients important for bone and joint health, such as calcium-rich foods, vitamin D, gelatine combined with vitamin D, and anti-inflammatory nutrients to include in their diet such as omega-3 fats, bioavailable curcumin and ginger may help them minimise pain and inflammation associated with these degenerative health complications, as outlined in Chapter 12.

According to Athlete 2, low back pain is rampant in amputees, and if an athlete does not keep up with active recovery modalities, such as self-myofascial release, stretching hip flexors, hamstrings, and glutes, and maintaining a strong core, this pain increases. Athlete 6 also stated his worry about increasing back problems as he ages since he swings his lower back to help move his legs. He states his knees won't bend if he does not apply enough forward pressure going heel to toe. Each leg weighs 5.5–7 kg and he often twists around to avoid taking more steps, causing strain on his back.

Athlete 3 expressed concern about daily life and ambulating becoming progressively challenging when she is older. Activities such as getting in and out of the shower, getting herself up and about and activities of daily living might become more difficult. She mentioned this giving her continued incentive to stay active and in good shape while she ages to help mitigate the effects of her concerns. Athletes 2 and 4 relayed concern for this same topic and the increase in overuse injuries. Aging concerns them and they are worried about further decline in the integrity of their joints, knees, and hips from the imbalance and load on their sound side.

Two of the female athletes interviewed discussed their concern about prosthesis fit and other issues with imbalance during potential future pregnancy. Athlete 5 discussed her experience of being pregnant twice and the challenges she experienced. She stated maintaining a healthy pregnancy weight as being impactful in minimising issues with her prosthesis fit. She said her back took the biggest toll and led her to discontinue running sooner than she expected due to the increase in compensation causing back pain. She switched to riding her bike indoors to minimise injury risk. Lastly, she mentioned going back to full-time training too quickly postpartum and injuring her sound leg from a lack of stability due to reductions in training intensity and volume decreasing her strength to adequately support her affected side.

In summary, athletes with an amputation have similar or potentially higher total energy and macro- and micronutrient needs compared with able-bodied athletes. Reasons for increased energy and nutrient needs include inefficiency of movement and overcompensation of intact limbs, poorly fitting prosthetics and associated inflammatory issues. Athletes with an amputation may deliberately dehydrate, depending on their level of injury and associated discomfort during exercise or travel. Most importantly, athletes with an amputation need to be individually assessed in order to optimise nutritional strategies. Practitioners working with athletes with an amputation, however, should also realise that these athletes are self-sufficient and are just as able to adopt healthy, performance-based strategies as able-bodied athletes.

8.5 ANTHROPOMETRY AND BODY COMPOSITION CONSIDERATIONS IN ATHLETES WITH AN AMPUTATION

As in able-bodied athletic populations, assessment of body composition can assist in evaluating the athlete with an amputation's health and fitness status. However, it is imperative to recognise that body composition methods have inherent problems of validity and reliability, even in the able-bodied population (Ackland et al. 2012;

Chapter 13). Body composition assessment in amputees is further complicated by the location and degree of amputation and the lack of standardised methods and normative data established in this population.

There are several methods to assess body composition. While Chapter 13 will focus in more detail on body composition assessment in Para athletes, this section summarises the key issues regarding the most common laboratory and field methods in the amputee population. For an excellent resource on body composition in chronic disease and impairments, see also Goosey-Tolfrey and Sutton (2012).

Densitometry such as hydrodensitometry or air displacement plethysmography (ADP) are common laboratory methods using a two-compartment model. While these methods already use invalid assumptions for the estimation of fat free tissue densities in able-bodied populations (Ackland et al. 2012), an additional concern in amputees is the reduced body volume as a result of missing a limb. In addition, amputees will also present lower whole-body BMD, which is a part of fat free mass (FFM) component and would therefore alter the estimate of muscle mass in amputees versus able-bodied counterparts (Van de Vliet et al. 2011).

Dual energy x-ray absorptiometry (DXA) uses a three-compartment model to measure fat, bone mineral and other fat-free soft tissues (Ackland et al. 2012) and shows the greatest potential to accurately measure body composition in the amputee population. The ability of DXA to measure specific body segments makes it an optimal choice where regional differences are of interest, such as the assessment of centre of mass for the purpose of optimising prosthetic fittings. It is also useful for monitoring body composition changes over time when following a standardised protocol. However, Para athletes with non removable metal implants or reinforcement may not be able to achieve an accurate result.

Body composition field methods include surface anthropometry, bioelectrical impedance analysis (BIA) and various others, some of which propose a combination of measures and are briefly discussed below. Surface anthropometry, if conducted by a trained International Society for Kinanthropometry (ISAK)-certified anthropometrist, is reliable (Chapter 13). Additional limb girths, bone lengths and bone breadths can be used to attain a more accurate representation of an individual's anthropometry. While ISAK does not preclude the use of raw skinfold data in estimating body density and percent body fat (% BF), it emphasises the sum of skinfolds and skinfold ratios over % BF, as these additional steps introduce error. Since there are currently no equations developed for amputees that convert the sum of skinfolds to body density and % BF, the sum of skinfolds should be reported in amputees. While ISAK standardisation requires skinfold measures to be taken on the right side of the body, this can be changed to the left side for an athlete missing a right limb and be noted by the anthropometrist for future reference and/or comparison. For further guidelines and tools specifically using ISAK methodology in populations with impairments, including amputees, see Chapter 13.

In addition to skinfold measurements, body mass plays a key role in surface anthropometry assessment. It is important wherever possible for amputees to be weighed without their prosthetic limbs or any liners to maintain consistency and standardisation. Prostheses may change over time and liners or socks may carry additional weight from sweat.

Determining stretch stature may require consideration and modification in athletes with lower limb amputations. Whether an athlete with an amputation has a unilateral or bilateral leg amputation, stretch stature may be difficult to measure. An athlete with a unilateral leg amputation will be standing on one leg for this measurement; this can alter the athlete's standing position and curvature of the spine; hence, care must be taken to ensure the stretch stature is appropriate and the athlete is able to remain stable while standing on one leg. Sitting height is a better tool for athletes with a bilateral leg amputation. If sitting height is used, it is crucial to note that it cannot be correlated with a stretch stature; it must be used as a stand-alone measure. The severity of amputation and impairment will determine the appropriate method of assessment.

Finally, BIA estimates total body water, % BF and fat free mass and assumes geometric similarity between subjects (Ackland et al. 2012), which is not met in amputee populations. BIA also under-represents the trunk over the extremities, which poses problems in some amputees, as the trunk may represent a larger proportion of their total body. If an athlete is able to successfully complete this assessment with either lower or upper limbs intact, values should still not be compared to normative data but to individual changes over time (Van de Vliet et al. 2011).

In summary, as outlined in Chapter 13, DXA and surface anthropometry using ISAK standards offer the most valid and reliable body composition assessment in athletes with an amputation. In order to further examine whether other parameters such as circumference measurements may prove useful in athletes with an amputation, ISAK-certified examiners could carefully monitor variables such as circumferences in addition to skinfolds.

8.6 FUTURE RESEARCH

There continues to be a need for research in athletes with an amputation. Studies are required to collect more information on energy expenditure in athletes with an amputation at rest, during activities of daily living and during various types of exercise using methods such as doubly labelled water and indirect calorimetry. Future research should also compare measured RMR to proportionally adjusted RMR using prediction equations in athletes with an amputation. Portable devices are available and should be used to measure VO_2 in athletes with various degrees of amputations participating in different sports in order to determine differences between types of amputations and sports and between able-bodied counterparts.

Studies should also include body composition of amputees, and sport scientists should establish validated norms for athletes with impairments. Due to the lack of nutrition data on athletes with an impairment, including amputees, research is not only needed that characterises the diets of athletes with an amputation but also their nutritional, micronutrient and hydration status. While it is assumed that fuelling needs are similar among athletes regardless of impairment, there is a need for research in athletes with impairments related to carbohydrate oxidation rates during exercise and post-exercise protein balance. Finally, research in this population should include impactful and updated micronutrient interventions to help support bone health, prevent injury and infection, relieve pain and decrease inflammation, increasing longevity in sport participation and overall health.

REFERENCES

Ackland, T.R., Lohman, T.G., Sundgot-Borgen, J. et al. 2012. Current status of body composition assessment in sport: Review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical Commission. *Sports Medicine* 42:227–249.

Ainsworth, B.E., Haskell, W.L., Herrmann, S.D. et al. 2011. Compendium of physical activities: A second update of codes and MET values. *Medicine and Science in Sports and Exercise* 43:1575–1581.

Bergeron, J.W. 1999. Athletes with disabilities. *Physical Medicine & Rehabilitation Clinics of North America* 10:213–228.

Bragaru, M., Dekker, R., Geertzen, J.H. and Dijkstra, P.U. 2011. Amputees and sports: A systematic review. *Sports Medicine* 41:721–740.

Buchholz, A.C. and Pencharz, P.B. 2004. Energy expenditure in chronic spinal cord injury. *Current Opinion in Clinical Nutrition and Metabolic Care* 7:635–639.

Clauser, C.E., McConville, J.T. and Young, J.W. 1969. Weight, volume, and center of mass of segments of the human body. In *AMRL Technical Report*, pp. 69–70. Wright-Patterson Air Force Base, Ohio: US Air Force.

Cunningham, J.J. 1980. A reanalysis of the factors influencing basal metabolic rate in normal adults. *American Journal of Clinical Nutrition* 33:2372–2374.

Dempster, W.T. 1955. Space requirements of the seated operator. In *WADC Technical Report*, pp. 55–159. Wright-Patterson Air Force Base, Ohio: US Air Force.

Dillingham, T.R., Pezzin, L.E. and MacKenzie, E.J. 2002. Limb amputation and limb deficiency: Epidemiology and recent trends in the United States. *Southern Medical Journal* 95:875–883.

Ferrara, M.S. and Peterson, C.L. 2000. Injuries to athletes with disabilities: Identifying injury patterns. *Sports Medicine* 30:137–143.

Gailey, R. and Harsch, P. 2009. Introduction to triathlon for the lower limb amputee triathlete. *Prosthetics and Orthotics International* 33:242–255.

Goosey-Tolfrey, V. and Sutton, L. 2012. Body composition in disease and disability. In *Body Composition in Sport, Exercise and Health*, eds. Stewart, A.D. and Sutton, L. pp. 166–186. Abingdon, UK: Routledge.

Holway, F.E. and Spriet, L.L. 2011. Sport-specific nutrition: Practical strategies for team sports. *Journal of Sports Sciences* 29(Suppl. 1):S115–S125.

Howell A., Pruziner A. and Andrews, A. 2015. Use of predictive energy expenditure equations in individuals with lower limb loss at seated rest. *Journal of Academy of Nutrition and Dietetics* 115:1479–1485.

International Paralympic Committee. 2015. *IPC Classification Code and Standards*. http://www.paralympic.org – The IPC – IPC Handbook (accessed July 1, 2018).

Jeukendrup, A., Carter, J. and Maughan, R. 2015. Competition fluid and fuel. In: *Clinical Sports Nutrition* (5th edn), eds. Burke, L. and Deakin, V. pp. 493–591. Sydney: McGraw-Hill.

Juzwiak, C.R., Winckler, C., Joaquim, D.P., Silva, A. and de Mello, M.T. 2016. Comparison of measured and predictive values of basal metabolic rate in Brazilian Paralympic track and field athletes. *International Journal of Sport Nutrition and Exercise Metabolism* 26:330–337.

Klenck, C. and Gebke, K. 2007. Practical management: common medical problems in disabled athletes. *Clinical Journal of Sports Medicine* 17:55–60.

Leclercq, M.M., Bonidan, O., Haaby, E., Pierrejean, C. and Sengler, J. 2003. Study of bone mass with dual energy x-ray absorptiometry in a population of 99 lower limb amputees. *Annals de Readaptation et de Medicine Physique* 46:24–30.

Litsky, F. 2001. Diana Goldon-Brosnihan dies at 38. *The New York Times* http://www.nytimes.com/2001/08/28/sports/diana-golden-brosnihan-skier-dies-at-38.html?src=pm (accessed October 20, 2018).

Melzer, I., Yekutiel, M. and Sukenik, S. 2001. Comparative study of osteoarthritis of the contralateral knee joint of male amputees who do and do not play volleyball. *Journal of Rheumatology* 28:169–172.

Mengelkoch, L.J., Kahle, J.T. and Highsmith, M.J. 2017. Energy costs and performance of transfemoral amputees and non-amputees during walking and running: A pilot study. *Prosthetics and Orthotics International* 41:484–491.

Meyer, N. and Marshall, S. 2014. Nutrition for Amputees. In *Sports Nutrition for Paralympic Athletes*, ed. Broad, E. pp. 107–126. Boca Raton: CRC Press, Taylor & Francis Group.

Nolan, L. 2008. Carbon fibre prostheses and running in amputees: A review. *Journal of Foot and Ankle Surgery* 14:125–129.

Osterkamp, L. 1995. Current perspective on assessment of human body proportions of relevance to amputees. *Journal of the American Dietetic Association* 95:215–218.

Pannek, J. and Wollner, J. 2017. Management of urinary tract infections in patients with neurogenic bladder: Challenges and solutions. *Research and Reports in Urology* 9:121–127.

Rastmanesh, R., Taleban, F.A., Kimiagar, M., Mehrabi, Y. and Salehi, M. 2007. Nutritional knowledge and attitudes in athletes with physical disabilities. *Journal of Athletic Training* 42:99–105.

Rice, I., Hettinga, F.J., Lafferrier, J. et al. 2011. Biomechanics In *The Paralympic Athlete* (1st edn), Vandlandewijck, Y.C. and Thompson, W.R. pp. 33–50. West Sussex, UK: Wiley-Blackwell.

Royer, T. and Koenig, M. 2005. Joint loading and bone mineral density in persons with unilateral, trans-tibial amputation. *Clinical Biomechanics* 20:1119–1125.

Scaramella, J., Kirihennedige, N. and Broad, E. 2018. Key nutritional strategies to optimize performance in Para athletes. *Physical Medicine and Rehabilitation Clinics North America* 29:283–298.

Schmalz, T., Blumentritt, S. and Jarasch, R. 2002. Energy expenditure and biochemical characteristics of lower limb amputee gait: The influence of prosthetic alignment and different prosthetic components. *Gait and Posture* 16:255–263.

Sherk, V.D., Bemben, M.G. and Bemben, D.A. 2008. BMD and bone geometry in transtibial and transfemoral amputees. *Journal of Bone Mineral Research* 23:1449–1457.

Shirreffs, S.M. and Sawka, M.N. 2011. Fluid and electrolyte needs for training, competition, and recovery. *Journal of Sports Sciences* 29(Suppl. 1):S39–S46.

Silva Gomes, A.I., Goncalves Ribeiro, B. and Abreu Soares, E. 2006. Nutritional profile of the Brazilian amputee soccer team during the precompetition period for the world championship. *Nutrition* 22:989–995.

Van de Vliet, P., Broad, E. and Strupler, M. 2011. In *The Paralympic Athlete*, eds. Vandlandewijck, Y.C. and Thompson, W.R. pp. 172–197. West Sussex, UK: Wiley-Blackwell.

Weyand, P.G., Bundle, M.W., McGowan, C.P. et al. 2009. The fastest runner on artificial legs: Different limbs, similar function? *Journal of Applied Physiology* 107:903–911.

Willick, S.T., Webbom, N., Emery, C. et al. 2013. The epidemiology of injuries at the London 2012 Paralympic Games. *British Journal of Sports Medicine* 47:426–432.

9 Other Physical Impairments

Elizabeth Broad

CONTENTS

9.1 INTRODUCTION

The scope of eligibility for participation in Paralympic sports is extremely wide. Those impairments not already described in this book include short stature, leg length difference and reduced passive range of motion (such as arthrogryposis). There are also some specific medical conditions which fall within other impairment types but have not been described, such as Friedreich's ataxia, multiple sclerosis, severe burns, polio, osteogenesis imperfecta, congenital limb deformities (such as club foot) and muscular dystrophies. Due to their relatively small numbers, very little is known about the impact of these impairments within an exercise environment; however, some valuable information can be gained from the clinical literature. This chapter describes some of these impairment types and provides insight into potential nutrition issues the athlete may face.

9.2 SHORT STATURE

Short stature generally refers to a group of genetic disorders characterised by shorter than normal skeletal growth caused by one of over 300 conditions. Achondroplasia is the most common cause of short stature, the majority of these individuals having average-sized parents. In achondroplasia, the head is relatively large and the trunk is a relatively normal length; however, the arms and legs are disproportionately short. Short stature may be disproportionate, in that one or more body parts are relatively large or small in comparison to those of an average-sized adult, or proportionate, whereby the body is normally proportioned but unusually small. Athletes with short stature are eligible to compete in athletics, badminton, equestrian, powerlifting, sailing, swimming and table tennis, with height limitations and classification requirements varying between sports.

While the majority of causes for short stature do not coincide with other medical conditions, it is important to know the primary diagnosis and cause of the athlete's short stature. Individuals with lifetime congenital growth hormone deficiency, one cause of short stature, who remain untreated display reduced β-cell function and a higher frequency of impaired glucose tolerance (Oliveira et al. 2012). While regular exercise is known to reduce insulin resistance and be protective against diabetes, it may be prudent to consider the use of a lower glycaemic index and glycaemic load of carbohydrate, and their timing, when managing an athlete who has congenital growth hormone deficiency (see Chapter 10 with regard to diabetes).

Little is known about the relative functionality of muscle or physiology of those with short stature. Muscle size is considered to predetermine muscle strength, and those with short stature have smaller muscle cross-sectional area and muscle fibre length than able-bodied controls (Sims et al. 2018). The results is a smaller specific force (15% smaller in the vastus lateralis; Sims et al. 2018). The reduced force may also be associated with tendon and ligament stiffness, the coactivation potential of other muscles or infiltration of fat into muscle fibres (Sims et al. 2018). Whether this also applies to athletes or the difference is reduced through training adaptations is unknown.

Some reports state that individuals with short stature experience difficulties in maintaining a healthy weight for height in adulthood (Hunter et al. 1996), although it may be particularly noticeable due to their short stature (Owen et al. 1990). There is limited research regarding the energy requirements of individuals with short stature, with only one study in individuals with achondroplasia indicating their resting metabolic rate (RMR) relative to fat free mass was higher than the reference, normal-height population (Owen et al. 1990). Interestingly, the researchers noted that the RMR calculated using the Cunningham equation (see Chapter 3, Table 3.1) overestimated the energy requirements of these individuals; however, there was no description of activity provided for these subjects. Specific RMR prediction equations were developed by Owen and colleagues (1990); however, the population was small ($n = 32$), the data have not been validated, and the authors themselves noted the variability between individuals and recommended assessment on a case-by-case basis in future. While it is likely that athletes who are of short stature have similar energy requirements per kg body mass to normal-height athletes in similar sports, in absolute terms, their energy requirements are reduced, which means that the nutrient density of their diets must be greater to ensure all nutrient requirements are adequately met. It may be necessary to specifically educate athletes with short stature to understand their own individual nutritional needs rather than being influenced by what other athletes eat, especially where body composition management is required.

Undertaking anthropometrical assessments in an individual of short stature is effectively the same as for a standard-height individual, although it must be acknowledged that reference data may not be relevant for comparison and many assumptions may be violated (see Chapter 13), especially where the body is disproportionately short. The use of dual-energy x-ray absorptiometry (DXA) for body composition, for example, may not be valid. Standard weight for height curves have been developed for individuals with achondroplasia ranging from birth to adulthood (Hunter et al. 1996), which can be useful when assessing growth and development of younger athletes or estimating appropriate weight for height in adults.

While this dataset is unique, it also has some limitations (particularly for adults) since it was based on 1147 observations undertaken on 409 Caucasian subjects, mostly during childhood. Waist to hip ratio and body mass index do not appear to be useful indicators of body fatness in this population (Hunter et al. 1996; Owen et al. 1990). Skinfold thicknesses were found to correlate with weight and body density in adults with achondroplasia, so they are believed to be a useful indicator of body fatness in this population (Hunter et al. 1996; Owen et al. 1990). Therefore, in the hands of an appropriately trained practitioner, skinfold measures most likely remain a relevant tool to use for athletes of short stature to assess body composition changes over time.

From a practical perspective, consideration must be taken in regards to catering and self-catering kitchen facilities in regards to safe and height relevant access to serveries, stovetops, ovens and benchtops.

COMMENTARY BOX 9.1

COACH'S INSIGHT: What do you think is the most important thing a sports nutrition practitioner can do to assist your athletes?

> Identify any specific impairment considerations from a nutritional standpoint. Once that has been highlighted and taught to the athlete, sport coach and support staff members, the entire performance team can effectively be on the same page. From a strength and conditioning standpoint, it is also great to complement the sports nutrition practitioner on any body composition goals, as well as pre- and postworkout fuelling and refuelling strategies.

Sam Gardner, US Paralympics Strength & Conditioning Coach

9.3 MULTIPLE SCLEROSIS

Multiple sclerosis (MS) is the most common degenerative autoimmune disorder of the central nervous system, resulting in a range of neurological symptoms depending on the site of inflammation and scarring of the myelin sheath around nerve fibres (Payne 2001). Symptoms can vary widely from person to person depending on the number and location of nerve fibres affected, and symptoms can change over time. Common symptoms of MS include numbness or weakness in one or more limbs; tremor, lack of coordination or unsteady gait; fatigue; tingling or pain; cognitive impairment and vision impairments. Complications associated with MS include problems with bowel or bladder function, forgetfulness and mood swings, muscle spasm, epilepsy and depression. There are several forms of MS depending on the nature of progression (e.g. relapsing-remitting, primary progressive or secondary/chronic progressive) and while the neurological dysfunction may be minimal in the early stages, it will progressively worsen. It is therefore more likely that individuals whose MS results in limitations that would enable them to be classified as an athlete with an impairment will have had the disease for some time and their neurological symptoms will most likely change and/or worsen in due course.

Athletes with MS need nutrition advice to account for their primary symptoms and the impact these have on motor function and hence energy requirements. A diet rich in essential fatty acids (omega-3 and omega-6 fatty acids) and low in saturated fatty acids via increased intake of fish, nuts, seeds and vegetable oils, and reduced animal fat intake, has been recommended due to their essential role in membrane phospholipids (Harbige and Sharief 2007; Payne 2001; Penesova et al. 2018). There has also been interest in the association between vitamin D and MS, in terms of both the risk of developing the disease and its management, the evidence for which has been reviewed by Solomon and Whitham (2010). They recommend screening individuals with MS for vitamin D status and supplementing where blood levels are deficient or insufficient. Indeed, a recent study supplementing individuals with MS with 2000 mg/d omega-3 fatty acids and 50,000 IU vitamin D3 every 2 weeks for 12 weeks improved functional ability scores and positively influenced many metabolic biomarkers (Kouchaki et al. 2018). Due to the multiple potential beneficial effects of fish oils, it would seem pertinent to supplement athletes with MS with a daily fish oil supplement, especially if their dietary fish intake is low. Similarly, restricting saturated fat intake and increasing intakes of antioxidant nutrients have been advised, as there are indications of increased oxidative stress in individuals with MS (Penesova et al. 2018). Where neurological changes impact gut motility or swallowing, increasing the respective fibre and/or fluid intake, and alterations in the consistency of food, are also advised (Payne 2001). Further benefits of adequate dietary fibre intake are that it ensures optimal gut microbiota and production of butyrate, which can be beneficial for brain neuronal function (Penesova et al. 2018).

Athletes with MS often have impaired thermoregulation, with even small increases in core temperature resulting in a worsening of symptoms, especially muscle fatigue (Davis et al. 2010). Sweat responses to heat and exercise may be reduced, which highlights the importance of undertaking sweat rate testing to best understand fluid needs. It is important to provide these athletes with resources to help limit a rise in core temperature during exercise, especially in the heat. Chapter 5 outlines ways to manage heat load before, during and after exercise.

9.4 FRIEDREICH'S ATAXIA AND MUSCULAR DYSTROPHIES

Muscular dystrophy is a range of neuromuscular disorders which involve the progressive and irreversible wasting of voluntary muscle tissue. There are approximately 60 muscular dystrophy diseases, each with a separate cause, and symptoms of the disorder and the muscles it impacts will vary across causes. Since the disease impacts muscle directly, the likely sports nutrition issues include a reduced energy expenditure and impaired fuel use during exercise, particularly the more immobile an athlete becomes. Athletes will need to be assessed on a case-by-case basis according to their functional capabilities, body size and the sport they are involved in.

Friedreich's ataxia is one form of muscular dystrophy and is a genetic disease causing progressive degeneration in the central and peripheral nervous systems, cardiomyopathy, skeletal abnormalities and an increased risk of diabetes (Pandolfo 2002; Santos et al. 2010). The neurological deficits result in a range of symptoms from muscle weakness to speech problems, with symptoms presenting before 22 years of age, and within 10–15 years, the majority of individuals require a wheelchair for mobility. Adults with Friedreich's ataxia have a substantially slower gait velocity, shorter steps and more variability in stride length than nonaffected individuals at both comfortable and fast walking speeds (Stephenson et al. 2015). How this impacts energy expenditure is uncertain; hence, practitioners should observe athletes in their daily training environment.

Friedreich's ataxia is caused by the decreased function of frataxin, a protein that binds iron in the mitochondrial matrix (Santos et al. 2010). Decreased frataxin function results in iron accumulation in the mitochondria, resulting in dysfunction of mitochondria, iron-mediated oxidative stress and iron depletion in the cytosol (Wilson 2012). This localised iron accumulation does not appear to be associated with systemic iron deficiency (Santos et al. 2010). A number of therapies are being trialled to manage this disease, each of which has a tendency for adverse outcomes related to iron (including low serum ferritin or elevated haematocrit; Nachbauer and Boesch 2011; Wilson 2012); therefore, it should be determined whether the athlete is on any treatment (and if so, which), since this may impact dietary iron requirements.

The combined use of 2100 IU vitamin E and 400 mg coenzyme Q10 daily over 4 years has been investigated to determine its potential to improve mitochondrial energy synthesis, improve cardiac function and slow the progression of certain clinical features of Friedreich's ataxia (Hart et al. 2005). The recommendation to increase antioxidant nutrient consumption in athletes remains valid in this population to help counterbalance the increased oxidative stress within the mitochondria.

9.5 SEVERE BURNS

Severe burns are not an eligible impairment type; however, they may coexist with another form of impairment. In the acute phase of healing from severe burns, energy and protein requirements are substantially higher than normal. Evidence suggests that an increased energy expenditure and negative nitrogen balance may persist for up to 18 months post–burn injury, but insulin resistance induced by this hypermetabolic response to burns can persist for up to 3 years (Gauglitz et al. 2009; Klein 2008). By the time a burn victim has healed sufficiently to become actively involved in exercise, this hypermetabolic response will most likely have resolved and their energy and protein requirements returned to normal; however, it is worthwhile investigating the period since the initial burn injury. Bone loss also occurs as a consequence of burns (Klein 2008); therefore, it is important to consider nutrition support which optimises bone mineralisation and limits any further loss of bone density for athletes who have burns.

One key nutrient which may be at risk of deficiency in burn victims is vitamin D. It has been reported that acute burn injury that covers 40% or more of the total body surface area is associated with reduction in bone formation and resorption, hypocalcaemia, hypercalciuria and hypoparathyroidism (Klein et al. 2004), the long-term outcome being reduced bone mineral density. Disruption to the skin integrity from burns has been shown to reduce both the levels of 7-dehydrocholesterol and also the percentage conversion to vitamin D_3, not only where the burn scar is but also in adjacent normal skin (Klein et al. 2004). Since the majority of vitamin D is obtained through skin exposure to ultraviolet B rays, serum 25-hydroxyvitamin D concentrations are consequently low (Klein 2008). This is exacerbated by a reluctance of individuals to expose their skin (particularly outdoors) and spend time outside since sweat glands are destroyed by the injury (Klein 2008). As outlined in Chapter 6, vitamin D deficiency has been associated with reduced bone mineral density, abnormalities in calcium homeostasis, reduced muscle strength and a disrupted immune response (Solomon and Whitham 2010), all factors which are important to prevent in order to optimise training capacity and the health and well-being of an athlete. Hence, it is recommended that athletes with severe burns be assessed at least annually for vitamin D status and supplemented appropriately (as outlined in Chapter 12).

Where a burn victim has substantial skin grafts, their response to heat from the perspective of both cutaneous vasodilation and sweat response is limited at the graft site, particularly in split-thickness grafts, and this is unlikely to recover over time (Crandall and Davis 2010). Donor sites appear to be unaffected, and while total sweat rates per area of normal skin may be higher in burn victims (Ben-Simchon et al. 1981), there is little clarity as to whether this compensatory sweating is effective in managing thermoregulatory capacity. Indeed, individuals who have skin grafts covering more than 40% surface area of their body are at higher risk for hyperthermia if exercising in the heat or exposed to hot conditions over an extended period of time (Ben-Simchon et al. 1981; Shapiro et al. 1982). Currently there is no published literature describing the sweat rates or fluid intake practises of athletes with severe burns or skin grafts. It is therefore important for the practitioner to investigate individual sweat rates in these athletes, and, where possible, changes in core temperature, and work with them to determine an individualised fluid intake plan and consider the need for alternative cooling devices when exercising in the heat.

The choice of anthropometrical assessment for athletes with severe burns may require modification depending on the location of those burns. Skin grafts, and sites where skin grafts have been taken from, have different compressibility of the skin, which may lead to difficulty in taking consistent skinfold measurements. An anthropometrist may choose to alter the location of a skinfold site (provided this is well documented and used consistently in repeat measurements), omit one site or elect not to take skinfolds in situations where skin grafts are widespread. In this case, alternative methods of body composition assessment may be considered, such as the use of dual energy x-ray absorptiometry or air displacement plethysmography, as discussed in Chapter 13.

COMMENTARY BOX 9.2

ATHLETE INSIGHT: What do you think is the most important thing a sports nutrition practitioner can do to assist you?

> My advice would be to be flexible with the information you've been taught. Nutrition is an ever-evolving, constantly changing field to us athletes and when you add in impairments to the mix, something that is so personal and specific to each athlete, your programs and information should be adaptable also.

Steve Serio, Wheelchair Basketball, 3-time Paralympian (Beijing, London – Bronze medal and Rio – Gold medal)

REFERENCES

Ben-Simchon, C., Tsur, H., Keren, G., Epstain, Y. and Shapiro, Y. 1981. Heat tolerance in patients with extensive healed burns. *Plastic and Reconstructive Surgery* 67:499–504.

Crandall, C.G. and Davis, S.L. 2010. Cutaneous vascular and sudomotor responses in human skin grafts. *Journal of Applied Physiology* 109:1524–1530.

Davis, S.L., Wilson, T.E., White, A.T. and Frohman, E.M. 2010. Thermoregulation in multiple sclerosis. *Journal of Applied Physiology* 109:1531–1537.

Gauglitz, G.G., Herndon, D.N., Kulp, G.A., Meyer, W.J. and Jeschte, M.G. 2009. Abnormal insulin sensitivity persists up to three years in pediatric patients post-burn. *Journal of Clinical Endocrinology and Metabolism* 94:1656–1664.

Harbige, L.S. and Sharief, M.K. 2007. Polyunsaturated fatty acids in the pathogenesis and treatment of multiple sclerosis. *British Journal of Nutrition* 98(Suppl. 1):S46–S53.

Hart, P.E., Lodi, R., Rajagopalan, B. et al. 2005. Antioxidant treatment of patients with Friedreich ataxia: A 4-year follow-up. *Archives of Neurology* 62:621–626.

Hunter, A.G.W., Hecht, J.T. and Scott, C.I., Jr. 1996. Standard weight for height curves in achondroplasia. *American Journal of Medical Genetics* 62:255–261.

Klein, G.L. 2008. The interaction between burn injury and vitamin D metabolism and consequences for the patient. *Current Clinical Pharmacology* 3:204–210.

Klein, G.L., Chen, T.C., Holick, M.F. et al. 2004. Synthesis of vitamin D in skin after burns. *Lancet* 363:291–292.

Kouchaki, E., Afarini, M., Abolhassani, J. et al. 2018. High dose ω −3 fatty acid plus Vitamin D3 supplementation affects clinical symptoms and metabolic status of patients with multiple sclerosis: A randomized controlled clinical trial. *Journal of Nutrition* 148:1380–1386.

Nachbauer, W. and Boesch, S. 2011. New advances in the treatment of Friedreich ataxia: Promises and pitfalls. *Clinical Investigation* 1:1095–1106.

Oliveira, C.R.P., Salvatori, R., Barreto-Filho, J.A.S. et al. 2012. Insulin sensitivity and β-cell function in adults with lifetime, untreated isolated growth hormone deficiency. *Journal of Clinical Endocrinology and Metabolism* 97:1013–1019.

Owen, O.E., Smalley, K.J., D'Alessio, D.A. et al. 1990. Resting metabolic rate and body composition of achondroplastic dwarfs. *Medicine* 69:56–67.

Pandolfo, M. 2002. Iron metabolism and mitochondrial abnormalities in Friedreich ataxia. *Blood Cells, Molecules and Diseases* 29:536–547.

Payne, A. 2001. Nutrition and diet in the clinical management of multiple sclerosis. *Journal of Human Nutrition and Dietetics* 14:349–357.

Penesova, A., Dean, Z., Kollar, B. et al. 2018. Nutritional intervention as an essential part of multiple sclerosis treatment. *Physiological Research* 67:521–533.

Santos, R., Lefevre, S., Sliwa, D., Seguin, A., Camadro, J. and Lesuisse, E. 2010. Friedreich ataxia: Molecular mechanisms, redox considerations, and therapeutic opportunities. *Antioxidants and Redox Signaling* 13:651–690.

Shapiro, Y., Epstein, Y., Ben-Simchon, C. and Tsur, H. 1982. Thermoregulatory response of patients with extensive healed burns. *Journal of Applied Physiology* 53:1019–1022.

Sims, D.T., Onambele-Pearson, G.L., Burden, A., Payton, C. and Morse, C.I. 2018. Specific force of the vastus lateralis in adults with achondroplasia. *Journal of Applied Physiology* 124:696–703.

Solomon, A.J. and Whitham, R.H. 2010. Multiple sclerosis and vitamin D: A review and recommendations. *Current Neurology and Neuroscience Reports* 10:389–396.

Stephenson, J., Zesiewicz, T., Gooch, C. et al. 2015. Gait and balance in adults with Friedreich's ataxia. *Gait and Posture* 41:603–607.

Wilson, R.B. 2012. Therapeutic developments in Friedreich ataxia. *Journal of Child Neurology* 27:1212–1216.

10 Vision and Hearing Impairment

Elizabeth Broad

CONTENTS

10.1 INTRODUCTION

Individuals with vision impairment (VI) compete in a range of sports and have several subcategories, and the terminology used to differentiate them is sport specific. The least affected may not require a support person during competition (such as athletics), but others will require a seeing guide, such as the lead rider on a tandem bike or a guide calling instructions in alpine skiing. Consequently, the practitioner could be advising both the vision-impaired athlete and their guide when providing sports nutrition advice. Many sports can be modified to enable participation by vision-impaired individuals, especially in ways that take advantage of other senses such as hearing. Some sports such as goalball, judo and five-a-side football are specifically for this class of athlete. Team sports involve balls containing bells so that athletes are able to hear their location, and to enable all categories to compete in these specialised sports at an equal level, blindfolds are used (other than the goalkeeper in football) and the audience is requested not to make any noise during play.

Deafness is defined (for the purposes of international sporting competitions) as having lost at least 55 decibels from normal values in the better hearing ear, although some countries may have different criteria for domestic competitions. Hearing impairment is not a category for competing in the Paralympic Games; however, there are other major competitions including the Deaf Summer and Winter Games

(Deaflympics) that run every 4 years, and others such as regional competitions, plus hearing-impaired individuals are often invited to compete in domestic competitions which include other athletes with an impairment. There may also be Para athletes who have a hearing impairment in addition to their primary classifiable impairment.

10.2 CHARACTERISTICS OF VISION IMPAIRMENT

The most prevalent causes of vision loss in most developed countries are age-related degenerative eye diseases such as macular degeneration, diabetic retinopathy, glaucoma and cataract. The vision impairment in Paralympic athletes is, however, more likely to be a result of retinitis pigmentosa, hereditary retinal disorders (such as congenital nystagmus, optic neuropathies and albinism), optic nerve hypoplasia and eye trauma. In developing countries, vision impairments in children are also due to infectious diseases such as toxoplasmic macular retinochoroiditis, retinal dystrophies and ocular malformation (Haddad et al. 2007).

Physiologically, there is no reason to believe there are any differences between athletes with VI and their able-bodied counterparts; however, balance and proprioception may be altered. Athletes with VI train and compete at a slower speed than their seeing counterparts. For example, the winning 400 m run times at the Rio 2016 Paralympic games were 50.22 s for the men's T11 (most vision impaired) and 47.15 s for T13 (least vision impaired) compared to the world-record 43.03 s for the men's 400 m Rio Olympic games results. However, it is unlikely that these differences in race times create any difference in sports nutrition requirements. The circadian rhythm of individuals with complete VI is longer than 24 h, which may influence their strength and reaction times, and hence the optimal time for competition and performance may vary over time and repeatability of performance tests may be reduced compared to a non-VI population (Squarcini et al. 2013). Whether this, or effects of VI on movement coordination and balance, are the reason why judo athletes with complete VI (B1 class) are less likely to win a fight or become a member of a national team (Mashkovskiy et al. 2018) are yet to be fully determined.

The Paralympic sports in which athletes with vision impairment are eligible to compete are listed in Table 10.1.

COMMENTARY BOX 10.1

COACH'S INSIGHT:
Vision-impaired athletes are slower partly due to the longer processing time required to determine their body position in relationship to their environment – for example, where are they in their lane, when the bend starts and finishes when running the bend on a track. In addition, some forms of VI are impacted by training load, so you cannot train them for as long and/or hard within an individual training session.

Iryna Dvoskina, Athletics coach (multiple Paralympic medallists)

TABLE 10.1
Paralympic Sports Open to Athletes with Vision Impairment

Sport	VI Classes	Notes
Athletics	T11, T12, T13 (track events) F11, F12, F13 (field events)	T/F11 must have a guide. T/F12 may choose to have a guide. T/F13 is not allowed a guide. T/F11 must wear an eye patch or opaque glasses. T11/12 who use a guide must be tethered to that guide throughout the race. Individual events are held for each class at international competitions.
Alpine ski	B1, B2, B3	Factored system in racing whereby more vision-impaired athletes' times are multiplied by a factor to create a more even playing field. Athlete races with guide preceding them, wearing a headset for communication.
Cycling	B1, B2, B3	Athletes compete on tandem bikes with the lead rider being the sighted guide.
Equestrian	Grade III – most vision impaired (equivalent to B1) Grade IV – less vision impaired (equivalent to B2)	
Five-a-side football[a]	B1 for on-field players B2/B3 for goalkeepers	All on-field players must wear a blindfold. Ball has bell in it.
Goalball[a]	All VI classed the same	Blindfolds are worn during play.
Judo[a]	B1, B2, B3 but compete in same weight class	
Nordic ski	B1, B2, B3	Factored system in racing whereby more vision-impaired athletes' times are multiplied by a factor to create a more even playing field. Athlete races with guide preceding them, wearing a headset for communication. Electronic rifles used in biathlon with an audio headset.
Rowing	All VI classed the same	Compete in team boat (four person with coxswain).
Swimming	S11, S12, S13	S11 must wear blacked-out goggles when competing. Athletes are allowed "tappers" at each end of the pool who tap them on the head or shoulder to notify them when they reach the end of the lane. Tappers are optional for S12 and S13 but compulsory for S11.
Triathlon	PTVI1, PTVI2, PTVI3	Sighted guide compulsory throughout the race for all VI classes, including tandem bike in cycle section. Sighted guide must swim beside or behind VI athlete but can be tethered at the hip.

[a] Sports where *only* athletes with vision impairment are eligible to compete.
NB. The lower the number, the greater the degree of vision impairment.

10.3 CAUSES OF VISION IMPAIRMENTS

10.3.1 Retinitis Pigmentosa

Retinitis pigmentosa is a group of genetic eye diseases that cause the progressive degeneration of photoreceptor cells in the retina resulting in a loss of vision. Initially, the individual may have difficulty seeing at night, but eventually their "field of vision" reduces, progressing from the periphery towards central vision. The loss of visual function is estimated to occur at a rate of 4–12% annually. The worldwide prevalence of retinitis pigmentosa is 1 in 4000 and may become manifest in childhood or adulthood (Rayapudi et al. 2013). The disease may occur alone or in conjunction with other eye or organ abnormalities, including Usher syndrome, which involves both vision and hearing impairments.

Several nutrition interventions have been investigated for individuals with retinitis pigmentosa, primarily in the form of fat-soluble vitamin supplementation. Berson (1999) suggests that consumption of 15,000 IU of vitamin A daily in supplemental form, under medical supervision, slows the rate of progression of the disease in some individuals and has a low risk of toxicity in those over 18 years of age. Vitamin E supplementation, however, should be avoided. There has also been a small number of studies investigating supplemental omega-3 fatty acids in slowing the progression of retinitis pigmentosa since individuals with the disease have significantly reduced plasma docosahexanoic acid (DHA), which appears to have an important function in the retina (Hodge et al. 2006). The outcomes of these studies show possible small benefits, but importantly no detrimental effects, on progression of the disease (Hodge et al. 2006). A more recent Cochrane review concluded that there was no evidence of benefit for either vitamin A or DHA (400–1200 mg/d) supplementation in the progression of the disease, although there were no adverse side effects reported, and their review found only three studies that met their selection criteria (Rayapudi et al. 2013). Consequently, it would appear prudent to advise athletes with retinitis pigmentosa to maintain an adequate intake of omega-3 containing foods such as oily fish, walnuts, flaxseed and canola oil and vitamin A intake; however, the potential value of high dose supplementation remains uncertain.

10.3.2 Diabetic Retinopathy

Diabetic retinopathy occurs when the blood vessels in the retina burst or are damaged and the blood leakage causes oedema in the retina. It is one of the known long-term complications of poorly controlled diabetes (Phillips and Deakin 2015), and due to the age of most athletes who will seek sports nutrition advice, it is most likely that they will have Type 1 diabetes rather than Type 2. The management of Type 1 diabetes relies on insulin injections or pumps. The inability to self-regulate insulin and other counter-regulatory hormones such as glucagon in Type 1 diabetes increases the risk of hypoglycaemia, which can be potentiated by exercise if insulin and carbohydrate intakes are not managed carefully.

A complete overview of the dietary management of athletes with diabetes is a topic that is beyond the scope of this chapter, and readers are referred to more specialised resources (e.g. Phillips and Deakin (2015), www.runsweet.com, and www.glycemicindex.com). Athlete management should always be undertaken in conjunction with their endocrinologist and/or diabetes educator and involves regular monitoring of blood glucose response to exercise on an individual basis. The use of real-time continuous glucose monitoring can be beneficial for athletes with Type 1 diabetes to help understand their blood glucose response to exercise, especially when exercise levels vary considerably: from day to day, increase as happens in a sports camp situation or in an athlete who trains up to 2–3 times on some days, but not every day. Algorithms have been developed to guide the reduction in insulin dose according to exercise type and duration (Yardley and Colberg 2017) and for carbohydrate intake in response to blood glucose levels during exercise (Riddell and Milliken 2011; Robertson et al. 2009). However, it is important to remember that blood glucose response to exercise can be variable even under standardised conditions and will also vary according to pre-exercise blood glucose concentration, fitness levels, age, body mass, intensity and duration of exercise (Robertson et al. 2009). Therefore, individual responses still need to be monitored and adjusted.

There are some key factors which are worth noting when working with an athlete who has diabetes. The current recommendations are to manage insulin doses around the carbohydrate requirements for exercise, as opposed to managing carbohydrate intake according to insulin (Yardley and Colberg 2017). Since exercise itself results in the insulin-independent uptake of glucose into muscles, in most instances less insulin is required around an exercise bout (particularly afterwards) than in a sedentary situation. While carbohydrate requirements during exercise do not differ from other athletes, the diabetic may need to be more strategic with consuming carbohydrate during and immediately after exercise in order to prevent declines in blood glucose concentrations. Patterns of carbohydrate intake across the day will also need to be more regimented in athletes with diabetes, and meal plans will require specificity, especially where the vision impairment limits the athlete's ability to read food labels and readily monitor portion sizes. Finally, it is not uncommon that there will be other nutritional requirements which require attention if there are other diabetes complications such as high blood pressure or renal failure.

10.3.3 Albinism

Albinism is a congenital disorder where there is partial or complete absence of pigment in the skin, hair and eyes due to a defect in the production of melanin. Albinism is associated with a number of vision defects, such as photophobia, nystagmus and astigmatism. An additional complication of albinism is an increased tendency to sunburn and develop skin cancers, which generally limits the skin exposure to sunlight of athletes with albinism, thus increasing the risk of low vitamin D status. As discussed in Chapters 4 and 12, vitamin D deficiency can impact exercise performance and health; therefore, all athletes with albinism should be screened for vitamin D status on an annual basis and supplemented as necessary (see Chapter 12).

10.3.4 Stargardt Disease

Stargardt disease, or fundus flavimaculatus, is an inherited juvenile form of macular degeneration which begins before 20 years of age and progresses to affect central more than peripheral vision.

Concerns have been raised that high intakes of vitamin A may increase the deterioration of vision in individuals with Stargardt disease (Federspiel et al. 2018). A recent systematic review, however, indicates there is limited evidence in humans to support this (Federspiel et al. 2018), but until further research is undertaken, it is prudent to discourage the use of any form of vitamin A supplementation in athletes with Stargardt disease.

Outside of vitamin A, the majority of nutrition interventions for macular degeneration (MD) have been investigated in older age–onset MD sufferers. Research has highlighted the potential roles of linoleic acid (being implicated in the progression of the disease), with omega-3 fatty acids and antioxidant nutrients including vitamin C, E, beta carotene, lutein, zeaxanthin, zinc and saffron all being investigated regarding potential protective effects against disease progression. There is consistent support for increased consumption of fish rich in omega-3 fatty acids in reducing the incidence of age-related MD (Chua et al. 2006), but not necessarily fish oil supplementation (Lawrenson and Evans 2015). Whether this is also relevant at younger ages has not been determined; however, there remains strong interest in the role of omega-3 oils, and a reduced ratio of omega-6:omega-3 fatty acid intake, in slowing the progression of a number of eye diseases (Fang et al. 2009). The research regarding the role of antioxidant and zinc supplements suggest small reductions in progression of age-related MD but remains limited (Berson 1999; Evans & Lawrenson 2017; Stone 2007), and the practitioner must be mindful of the evidence linking antioxidant supplementation with reduced adaptation to exercise (as discussed in Chapter 3), and high doses of some vitamins and zinc can have adverse effects such as increased incidence of cancer and Alzheimer's disease (Stone 2007). Consuming a diet rich in lutein- and zeaxanthin-rich foods, such as carrots and green leafy vegetables (such as kale and spinach), may improve macular pigment levels in individuals who initially have low levels of macular pigment (Graydon et al. 2012), and lutein has been shown to inhibit the expression of the proinflammatory gene cyclooxygenase-2, which has been linked to the pathogenesis of age-related MD (Fang et al. 2009). Finally, recent research indicates the potential for 20–30 mg/d saffron to be effective in improving vision in the early stages of MD (Piccardi et al. 2012; Lashay et al. 2016). Whether this is related to the antioxidant properties of saffron or other mechanisms is unknown. Therefore, in line with current nutrition recommendations for optimal health and performance, there is efficacy in encouraging athletes with Stargardt disease to consume at least 2–3 servings of oily fish/week and maintain a diet rich in antioxidant nutrients, carotenoids and zinc sourced from foods (such as brightly coloured fruit and vegetables, wholegrain cereals and animal products) but avoid supplements containing vitamin A.

10.4 DIETARY INTAKES AND NEEDS OF ATHLETES WITH VISION IMPAIRMENT

Only two studies have reported energy requirements or dietary intakes of athletes with VI. Both studies were undertaken on Brazilian track and field athletes, with a range of impairments involved (Joaquim et al. 2018; Juzwiak et al. 2016). In a group of 11 international level runners and throwers in the T11 and T12 classes, their measured resting metabolic rate (RMR) averaged 5825 kJ (1387 kcal)/d for females (n = 4) and 5990 kJ (1426 kcal)/d for males (n = 7; Juzwiak et al. 2016). The authors determined that the Mifflin et al. (1990) and Owen et al. (1986, 1987) equations provided close estimates of resting energy requirements in these athletes. In a separate study using a similar population of 10 sprinters (4 male, 6 female) during a testing camp, where dietary intakes were assessed using photographic records taken by one of the researchers, athletes with VI were reported to consume an average of 9500 kJ (2262 kcal)/d (Joaquim et al. 2018). Fat free mass (FFM) was assessed via skinfold measures converted to % body fat, and energy expenditure of exercise was assessed via actigraphy. While the athletes were not attempting to lose weight during the camp, their energy availability was calculated to average 150 kJ (36.3 kcal)/kg FFM/d over the 4 days assessed, which would classify them to be in reduced energy availability. Acknowledging the potential limitations of indirect measures of energy expenditure and body composition, these results are in line with reports from other Para athlete populations and highlight the importance of educating athletes regarding appropriate dietary intakes to support optimal training and performance.

10.5 INFLUENCE OF VISION IMPAIRMENT ON CIRCADIAN RHYTHM AND SLEEP

It is recognised that many human biological systems fluctuate according to a “near” 24-hour circadian rhythm. The natural sleep-wake cycle and body temperature are the most obvious; however, there are several hormonal and performance parameters that are known to change according to the time of day. Circadian rhythms, however, are intrinsically slightly longer than 24 hours (23.8–25.1 h; Quera Salva et al. 2017), and humans rely on retinal exposure to daylight in order to synchronise with the solar environment that governs our 24-hour clock. Athletes with VI who have no light perception can develop poor circadian rhythm synchronisation (otherwise known as non-24-h sleep-wake rhythm disorder or non-24SWRD) which can impact their sleep patterns, athletic performance, neural functioning (learning, memory, cognition) and other behaviours (Quera Salva et al. 2017). These athletes often have progressive delay in their sleep-wake patterns accompanied by an increase in sleep onset latency (time between going to bed and falling asleep) and daytime sleepiness. Since it is not uncommon for athletes to experience sleep disruption at times, proper diagnosis of non-24SWRD is important and should be undertaken by an experienced sleep specialist so that the most appropriate management can be applied.

SPECIAL COMMENTARY: SLEEP, ATHLETES AND NUTRITION

Important components of training for athletes are many recovery and adaptation processes that occur during sleep. Acute/short-term sleep deprivation can result in reduced endurance performance; increased inflammation; reduced immune function; and altered learning, memory, cognition and pain perception. Chronic sleep deprivation can result in altered fuel metabolism, suppressed protein synthesis and altered mood states, which can all negatively affect athletic performance.

Athletes are recommended to have 8 hours sleep/night; however, it's not uncommon for Para athletes to experience disrupted sleep patterns for a variety of reasons including involuntary muscle spasm, pain, the impact of neurological disturbances and medications and disrupted circadian rhythms (e.g. athletes with VI). Sleep disturbances in able-bodied athletes have been reported to occur before important competitions as well as during normal training (Halson 2014). For both populations, sleep may be disrupted due to travel across time zones, when, despite sufficient time spent in bed, athletes can experience a delayed onset of sleep and lower sleep quality through the night.

Athletes who experience regular sleep disturbances should be referred to a sleep specialist and/or sport psychologist for assessment. Putting in place the following consistent, practical strategies to optimise sleep should work well for most people:

- Dark room with little noise (use of ear plugs or soft music, for example)
- Comfortable bed and pillow, including room temperature and bed clothing being appropriate
- Developing a consistent presleep routine, such as going to bed at the same time each night
- Limiting exposure to screens and light such as phones, TV, computers in the hour before going to bed
- Avoiding exercise or a hot bath within 2 hours of going to bed
- Avoiding caffeine in the late afternoon and evening
- Taking a short nap (<1 hour) during the middle of the day

There are also some nutrition strategies which may support sleep in athletes.

- Tart cherry juice – 240 mL or 30 mL concentrate around 1 hour before bed.
- Zinc – ensure adequate dietary intake through food wherever possible. Consider elemental zinc supplement if adequate dietary intake is not possible and athlete experiences sleep disturbances.
- Avoid extreme high or low carbohydrate intakes.
- Consume a balanced diet with sufficient protein in the evening a few hours before bed. Animal proteins are both higher in tryptophan (the amino acid precursor to serotonin, important for sleep) and zinc so should be encouraged in the evening meal/snack time (e.g. beef, pork, milk and yogurt).
- If travelling across multiple time zones, 3 mg melatonin may be useful to take an hour before bed time for the first three nights to assist in adapting sleep to the new time zone.

The use of melatonin as a supplement should be discussed with a sports medicine practitioner to ensure appropriate safety and dosage.

In addition to potential sleep disturbances, the variation in circadian rhythm from the typical 24 hours in athletes with complete VI may influence athletic performance. Research in athletes indicates heart-rate based tests and prolonged submaximal exercise undertaken in the heat are performed better in the morning when heart rate response to exercise and core body temperature is lower (Atkinson and Reilly 1996). Muscle strength and reaction times may be lower in the afternoon. The optimal time for competition and performance in athletes with VI may therefore vary over time and repeatability of performance tests may be reduced compared to a non-VI population (Squarcini et al. 2013). However, there is also evidence that there are individual differences in performance rhythms which may override the average population's circadian variance (Atkinson and Reilly 1996). Consequently, individual assessments should be made on athletes with VI to determine their personal circadian variance in performance so that modifications to training type, load and expectations can be made.

10.6 PRACTICAL ISSUES FOR ATHLETES WITH A VISION IMPAIRMENT

To optimally support athletes with vision impairments, it is important for the sports nutrition practitioner to discuss openly how best to provide information (e.g. written or verbal) and to understand the athlete's range and accuracy of vision. There are many tools to help those with VI, including magnification/large font, and programs which can convert documents and text to voice. It may be better to provide a voice recording of your notes than a written form.

When asking athletes with VI about their dietary intake, it is important to understand how they assess the size of a portion and the components of a mixed meal. Written food diaries may be inappropriate, especially if details on food and fluid quantities are required. While taking photos can be an appropriate alternative, it may also prove to be unreliable. Therefore, pairing an athlete with an observer may be the best option where accuracy in detail is required. Similarly, when educating athletes about how much and what to eat, use examples that they can feel or touch, such as the size of their fist, the size of a plate or glass, the weight of a spoon or scoop of an item, the proportions on their plate or the depth of a bowl.

Much of the sports nutrition advice for athletes with vision impairment will be centred around practical modifications and applications. For example, vision impairments prevent athletes from being able to drive, so they are usually dependent upon public transport or transport by other individuals. Taking public transport to and from training and sporting venues usually extends the time frame of travel, but can also present an opportunity to eat and drink. Therefore, pretraining and recovery nutrition suggestions need to be portable and the time spent in travel needs to be incorporated into meal plans. Similarly, vision-impaired athletes are less able to recognise dehydration status through visual cues so may require additional external support (e.g. a support person to undertake first morning urine-specific gravity measurements) when educating them about hydration and the impact of training and environment on this.

Crucial to providing sports nutrition advice will be an understanding of how food is accessed and how portion sizes and food choices are managed by the athlete. It is important to work on empowering the athlete to be proactive and independent in this whilst being sensitive to their reality. Encouraging an athlete who is completely blind to cook for themselves introduces potential safety risks (both physical and food safety), so helping them find solutions that meet their sports nutrition needs appropriately is important. Using an oven rather than a stovetop may be safer, and it is possible to use their other senses (such as hearing or touch) to determine whether something is cooked. For example, scrambled eggs make a different sound in the pan when they're cooked than when they're not cooked. The feel of a fork going through meat or chicken changes according to how well cooked it is. When shopping for food, vision impaired athletes can use customer service at supermarkets to assist them, so be specific about brands and names of foods that you advise them to get. Many supermarkets also provide online shopping opportunities which can be useful. Finally, there are several international apps that individuals with VI can use to assist them with many day-to-day needs. For example, "be my eyes" (https://www.bemyeyes.com/) and AIRA (https://aira.io/).

Athletes with VI (especially total VI) generally experience heightened acuity in their other senses. Hearing can be extremely sensitive, such that they will be able to hear your movements and voice well before you think they can. One athlete expressed this as "sometimes I want to ask people to stop breathing because it's so noisy!" Other senses that can be heightened are taste and smell, which can result in aversions and sensitivities to foods simply because the smell, taste or texture are overpowering to their senses. Awareness of this is important when creating meal plans and menus for travel.

It is important to ensure sports nutrition advice promotes optimal nervous system function in order for the athlete to optimise their sensory receptors. As discussed in Chapter 3, maintaining adequate blood glucose concentrations and optimising hydration status are useful for ensuring optimal nervous system functioning. Chapter 15 provides additional practical advice for these athletes.

COMMENTARY BOX 10.2

ATHLETE'S INSIGHT: What do you think is the most important thing a sports nutrition practitioner can do to assist you?

> One of the most useful things a sports nutrition practitioner can do is provide information on portions and food variety in a really accessible format. For example, come into the dining hall and let me feel the weight of a spoon of rice or a portion of protein you want me to eat. Teach me the "lingo" to use when I'm asking someone to serve me food – such as a fist size, palm size or a deck of cards, rather than the weight, volume or calories.

Lex Gillette, four-time Paralympic silver medallist, three-time World Champion and current World record holder (6.73 m) in long jump (F11).

10.7 HEARING IMPAIRMENT

There are several causes of hearing impairment, including injury, disease and genetic defects. Usher syndrome involves a combination of vision and hearing impairment. The most common adjustment required for athletes with a hearing impairment is a visual form of the starter's gun, such as a starting light, to replace the auditory one. Coaches may also have to modify their communication process, for example in swimming, when hearing aids are unable to be used during aquatic training sessions. When educating an individual with a hearing impairment, it is important to speak directly to their face and provide written support wherever possible. It is also useful to check their understanding of what you have said to ensure the correct message has been received.

10.8 SUMMARY AND TAKE-HOME MESSAGES

Athletes with VI can be a unique population of athletes to work with. Getting accurate information on their dietary intake can be more difficult to achieve, and modifications to the ways the practitioner provides education and advice to optimise nutrition for training and competition are required. Education on appropriate serving sizes and energy/nutrient intakes may require additional explanation and need to involve other individuals who are responsible for serving athletes with VI. Educational material may need to use a larger font or be delivered by voice. The athlete themselves can inform you how best to provide information and can help problem solve how you get useful information from them. Specific nutrients may require additional attention depending on the cause of their VI. Finally, asking questions around sleep and body clock can be useful in helping the athlete optimise these aspects of performance.

COMMENTARY BOX 10.3

ATHLETE'S INSIGHT: What are the biggest nutrition challenges you face? In particular, are there any that appear to be different challenges to what your able-bodied counterparts face?

> One of the biggest challenges is managing the portion sizes of what I eat. I have pretty good self control and if I had to fix my own plate of food I could visualise my own plate and what needs to be on it. However, I rely on other people to get food from the servery for me (at the training centre) and it's not the same person every day, so even though I tell them what I want, they serve me what they think they need to and sometimes that's more than what I'd eat. I was brought up to finish everything on my plate and so even if there's a lot of food on my plate I will still eat it all.

Lex Gillette, four-time Paralympic silver medallist, three-time World Champion and current World record holder (6.73 m) in long jump (F11).

REFERENCES

Atkinson, G. and Reilly, T. 1996. Circadian variation in sports performance. *Sports Medicine* 21:292–312.

Berson, E.L. 1999. Nutrition and retinal degenerations. In: *Modern Nutrition in Health and Disease*. Eds. Shils, M.E., Olson, J.A., Shike, M. and Ross, A.C. pp. 1491–1501. Baltimore: Williams & Wilkins.

Chua, B., Flood, V., Roohtchina, E., Wang, J.J., Smith, W. and Mitchell, P. 2006. Omega 3 fatty acids and age-related macular degeneration. *Archives of Opthalmology* 124:981–986.

Evans, J.R. and Lawrenson, J.G. 2017. Antioxidant vitamin and mineral supplements for slowing the progression of age-related macular degeneration. *Cochrane Database of Systematic Reviews* 7:CD000254.

Fang, I., Yang, C., Yang, C. and Chen, M. 2009. Comparative effects of fatty acids on proinflammatory gene cyclooxygenase 2 and inducible nitric oxide synthase expression in retinal pigment epithelial cells. *Molecular Nutrition and Food Research* 53:739–750.

Federspiel, C.A., Bertelsen, M. and Kessel, L. 2018. Vitamin A in Stargardt disease – An evidence-based update. *Ophthalmic Genetics* 25:1–5.

Graydon, R., Hogg, R.E., Chakravarthy, U., Young, I.S. and Woodside, J.V. 2012. The effect of lutein- and zeathanin-rich foods v. supplements on macular pigment level and serological markers of endothelial activation, inflammation and oxidation: Pilot studies in healthy volunteers. *British Journal of Nutrition* 108:334–342.

Haddad, M.A.O., Sei, M., Sampaio, M.W. and Kara-Jose, N. 2007. Causes of visual impairment in children: A study of 3210 cases. *Journal of Pediatric Ophthalmology and Strabismus* 44:232–240.

Halson, S.L. 2014. Sleep in elite athletes and nutritional interventions to enhance sleep. *Sports Medicine* 44:S13–S23.

Hodge, W.G., Barnes, D., Schachter, H.M. et al. 2006. The evidence for efficacy of omega-3 fatty acids in preventing or slowing the progression of retinitis pigmentosa: A systematic review. *Canadian Journal of Opthalmology* 41:481–490.

Joaquim, D.P., Juzwiak, C.R. and Winckler, C. 2018. Do Paralympic track and field athletes have low energy availability? *Revista Brasileira de Cineantropometria e Desempenho Humano* 20:71–81.

Juzwiak, C.R., Winckler, C., Joaquim, D.P., Silva, A. and de Mello, M.T. 2016. Comparison of measured and predictive values of basal metabolic rate in Brazilian Paralympic track and field athletes. *International Journal of Sports Nutrition and Exercise Metabolism* 26:330–337.

Lashay, A., Sadough, G., Ashrafi, E., Lashay, M., Movassat, M. and Akhondzadeh, S. 2016. Short-term outcomes of saffron supplementation in patients with age-related macular degeneration: A double-blind, placebo-controlled, randomized trial. *Medical Hypothesis, Discovery & Innovation Ophthalmology Journal* 5:32–38.

Lawrenson, J.G. and Evans, J.R. 2015. Omega 3 fatty acids for preventing or slowing the progression of age-related macular degeneration (review). *Cochrane Database of Systematic Reviews* 4:CD010015.

Mashkovskiy, E., Magomedova, A. and Achkasov, E. 2018. Degree of vision impairment influence the fight outcomes in the Paralympic judo: A 10-year retrospective analysis. *Journal of Sports Medicine and Physical Fitness*. Epub ahead of print doi: 10.23736/S0022-4707.18.08232-4.

Mifflin, M.D., St Jeor, S.T., Hill, L.A., Scott, B.J., Daugherty, S.A. and Koh, Y.O. 1990. A new predictive equation for resting energy expenditure in healthy individuals. *American Journal of Clinical Nutrition* 5:241–247.

Owen, O.E., Holup, J.L., D'Alessio, D.A. et al. 1987. A reappraisal of the caloric requirements of men. *American Journal of Clinical Nutrition* 46:875–885.

Owen, O.E., Kavle, E., Owen, R.S. et al. 1986. A reappraisal of caloric requirements in healthy women. *American Journal of Clinical Nutrition* 44:1–19.

Phillips, P. and Deakin, V. 2015. Special needs: The athlete with diabetes. In: *Clinical Sports Nutrition* (5th edn). Eds. Burke, L. and Deakin, V. pp. 647–668. Sydney: McGraw-Hill.

Piccardi, M., Marangoni, D., Minnella, A.M. et al. 2012. A longitudinal follow-up study of saffron supplementation in early age-related macular degeneration: Sustained benefits to central retinal function. *Evidence-Based Complementary and Alternative Medicine* 2012: article ID 429214.

Quera Salva, M.A., Hartley, S., Leger, D. and Dauvilliers, Y.A. 2017. Non-24-hour sleep-wake rhythm disorder in the totally blind: Diagnosis and management. *Frontiers in Neurology* 8:686.

Rayapudi, S., Schwartz, S.G., Wang, X. and Chavis, P. 2013. Vitamin A and fish oils for retinitis pigmentosa. *Cochrane Database of Systematic Reviews* 12:CD008428.

Riddell, M.C. and Milliken, J. 2011. Preventing exercise-induced hypoglycaemia in Type 1 diabetes using real-time continuous glucose monitoring and a new carbohydrate intake algorithm: An observational field study. *Diabetes Technology and Therapeutics* 13:1–7.

Robertson, K., Adolfsson, P., Scheiner, G., Hanas, R. and Riddell, M.C. 2009. Exercise in children and adolescents with diabetes. *Pediatric Diabetes* 10(Suppl. 12):154–168.

Squarcini, C.F.R., Pires, M.L.N., Lopes, C. et al. 2013. Free-running circadian rhythms of muscle strength, reaction time, and body temperature in totally blind people. *European Journal of Applied Physiology* 113:157–165.

Stone, E.M. 2007. Macular degeneration. *Annual Reviews of Medicine* 58:477–490.

Yardley, J.E. and Colberg, S.R. 2017. Update on management of Type 1 diabetes and Type 2 diabetes in athletes. *Current Sports Medicine Reports* 16:38–44.

11 Intellectual Impairments

Elizabeth Broad

CONTENTS

11.1 INTRODUCTION

Intellectual impairments, as outlined in Chapter 2, are currently included in a limited range of Paralympic Games sports such as table tennis, swimming and athletics. Additionally, they are included in a range of other major sporting events, including the Summer and Winter Special Olympics World Games, which are also run every 4 years. The most recent Summer Special Olympics World Games held in 2015 attracted over 6500 athletes from 177 countries. Intellectual impairments cover a broad spectrum of disorders, with the overriding requirement being an IQ less than 75, age of onset under 18 y and limitations in adaptive behaviour (such as self-care, communication, social interaction and learning). There are a range of diagnoses, which includes Down syndrome, autism spectrum disorder and Asperger syndrome. Some intellectual impairments also coincide with other clinical issues, including epilepsy, visual and auditory defects and congenital heart disease.

Limited research is available on athletes with intellectual impairments; however, there has been interest in nonathletes from the perspective of health since a lack of mobility and physical activity contributes to early mortality in this population (Fernhall and Pitetti 2001). In a review of studies investigating physical work capacity of individuals with intellectual impairments, where care was taken to adequately familiarise participants with testing procedures, Fernhall and Pitetti (2001) reported lower than average maximal aerobic capacity (VO_{2max}) in all but one cohort of runners. Van de Vliet et al. (2006) reported poorer strength and cardiorespiratory endurance capacity in elite athletes with intellectual impairment compared to athlete controls, but higher upper body muscle endurance and flexibility. Down syndrome individuals have the lowest values, likely due to their sedentary lifestyle, low maximal heart rate and poor leg strength. These data may be skewed, however, since many studies use subjects from institutions or specific care facilities. By the very nature of their classification criteria, athletes with intellectual impairment will likely exhibit some limitations to learning. This can be exhibited in their more limited ability to pace themselves in training and racing (Van Biesen et al. 2017), as well as a more limited ability to perform dual tasks such as balancing and tracking objects at the same time (Van Biesen et al. 2018). Nevertheless, the adaptive response to exercise (both aerobic and strength) training appears to be in line with general population (Frey et al. 1999; Pitetti and Tan 1991; Tsimaras et al. 2001; Tamse et al. 2010). It is important to note that athletes with intellectual impairments appear to require more opportunities to familiarise themselves with testing equipment and procedures in order to be able to provide reproducible, meaningful results for physiological testing, and this should be a requirement of any research studies in this population (Fernhall and Pitteti 2001).

COMMENTARY BOX 11.1

COACH'S INSIGHT: What do you think is the most important thing a sports nutrition practitioner (SNP) can do to assist your athletes?

> Our SNP serves a lot of roles so it's hard to single out a single most important thing she does. On a very general level, being a steady voice that reassures and serves as a point of confidence is very, very important

Adam Bleakney, Wheelchair T&F coach for over 13 years, coach of multiple Paralympic medallists from 100 m to marathon. Three-time Paralympian, Athens silver medallist 800 m.

11.2 AUTISM SPECTRUM

Autism spectrum, or more broadly Autism Spectrum Disorders, are a range of disorders characterised by significant and chronic impairment in a number of different neurodevelopmental areas. In particular, social interaction (especially the perception of social cues); communication skills (verbal and nonverbal) and restricted, repetitive or obsessive behaviour patterns. Symptoms are typically noticed between 1 and 2 years of age. The American Psychiatric Association (2013) DSM-5 defines the autism spectrum disorders to encompass the previous diagnoses of autism, Asperger syndrome, pervasive developmental disorder not otherwise specified and childhood disintegrative disorder. Asperger syndrome is more uniquely characterised by difficulties specifically with nonverbal communication, restricted and repetitive behaviours and physical clumsiness, while their linguistic skills and cognitive development are preserved.

One aspect that can be challenging with autism spectrum is that the repetitive behaviour patterns can include behaviours relating to food and feeding. Some individuals may have a restricted range of food choices (e.g. only consuming a specific colour of food or foods of a particular texture) and may be very resistant to introducing new foods or fluids, or new eating routines and behaviours (such as consuming a snack after exercise). The practitioner must ask questions relating to food preferences and understand the willingness of the athlete to change in order to provide the most appropriate advice. Carers will be important to include in consultations.

11.3 DOWN SYNDROME

Down syndrome (DS, also known as Trisomy 21) is a genetic condition which leads to physical and development delays and is responsible for about one-third of all cases of moderate to severe intellectual impairment (Hayes and Batshaw 1993). Individuals with DS display joint laxity, muscle hypotonia, reduced strength and a more unstable gait in walking (Agiovlasitis et al. 2011b). Additionally, they have higher rates of autoimmune diseases, epilepsy, hearing loss, morbidity and mortality than the general population (Hayes and Batshaw 1993; McKelvey et al. 2012), resulting in a reduced life expectancy which may be improved by involvement in regular physical exercise.

Aerobic capacity has been reported to be lower in DS than both the general population (Fernhall and Pitetti 2001; Fernhall et al. 1996) and compared to other intellectually impaired individuals; however, whether this is associated with reduced mobility resulting from muscle hypotonia and strength, reduced maximal heart rate or other reasons (such as lifestyle) is unknown. Balic et al. (2000) found higher aerobic capacity, maximal heart rate, endurance times and muscle strength in a DS group who had trained an average of 4.9 h per week for at least 1 year in order to compete in the Special Olympics compared to sedentary DS adults. This was supported in a 12-week study of either interval or continuous aerobic training (versus sedentary controls) in adults with DS, with a greater loss of weight in those undertaking the interval training (Boer and Moss 2016). Although there can be positive responses in these variables as a result of structured training, the values remain low compared to results frequently reported in the general population, and some exercise training programs undertaken in children and adolescents with DS have failed to produce measureable changes in cardiovascular capacity despite improvements in performance capabilities (Gonzalez-Aguero et al. 2010). While it is unlikely that individuals with DS have the ability to develop physiological capabilities similar to elite able-bodied athletes, they can certainly improve strength and physical performance through regular training. Whether fuel contributions to exercise are different due to their poorer cardiovascular capabilities is unknown.

11.4 SPORTS NUTRITION ISSUES WITH INTELLECTUAL IMPAIRMENTS

Only one assessment has been undertaken on nutrition needs of intellectually impaired athletes, and it was limited to those aged 2–13 y, primarily with Down syndrome (Gibson et al. 2011). The most common nutrition problems reported were oral motor problems, including difficulty chewing, swallowing or choking, plus dental problems, food allergies/intolerances and constipation, with 84% of parents reporting problems with their child eating too much/too little and refusing many foods (Gibson et al. 2011). Although the data may have been skewed by the self-report, voluntary nature of the investigation, managing sports nutrition requirements of athletes with intellectual impairments can be complicated and generally requires patience, some problem-solving skills and reiteration. It is imperative that a team approach be used, involving parents/carers, the coach and other professionals (such as sport psychologist) both to ascertain correct self-reporting, aid reinforcement of messages and resolve any underlying feeding limitations.

11.4.1 Body Composition

There is a Special Olympics International Health Promotion Database which is collecting basic body composition data over time in athletes participating in the Special Olympics. Higher levels of overweight and obesity (using body mass index, BMI) have been reported in the Special Olympics population (Temple et al. 2014). It was reported that 5.5% were underweight, while 56.8% were overweight or obese using standard BMI criteria. Unfortunately, to date there is no data in Paralympians with intellectual impairments and it is important to acknowledge the limitations of BMI as an indicator of body fatness in athletes.

Individuals with Down syndrome are shorter than the general population by up to 20 cm, or more than 2 standard deviations below the mean (Angelopoulou et al. 1999; Baptista et al. 2005), primarily due to disproportionate growth retardation of the legs (Barden 2003). As a consequence, growth curves in children and adolescents have been developed specifically for Down syndrome (Hayes and Batshaw 1993) and the validity of body mass index (BMI) as an indicator of obesity may be questionable. Using BMI as a measure of obesity, Melville et al. (2005) found a greater incidence of obesity in adult women with Down syndrome (in fact, only 26% of the women were in the normal range) but not in men compared with non-DS intellectually impaired adults, and higher BMI in DS women but not men were reported compared to non–intellectually impaired controls (Angelopoulou et al. 1999; Baptista et al. 2005). Bronks and Parker (1985) also undertook somatotype ratings in a DS population which classed them as predominantly mesomorphic-endomorphs, although this is not surprising considering the relative shortness of their legs would result in low ectomorphy ratings.

Estimates of body fat using skinfold and girth measures and a non–population-specific equation showed higher percentage body fat than comparison groups. Through undertaking DXA scans, others argue that total body fat levels are not necessarily higher, but rather differently distributed (with a higher fat mass in the truncal region), at least in children and adolescents with Down syndrome (Gonzalez-Aguero et al. 2011). This has been shown to hold true for adult males despite a significantly lower muscle mass compared to controls, but not for females, who displayed both higher fat mass and lower muscle mass (Baptista et al. 2005). Similarly, Usera et al. (2005) found there was a poor relationship between estimating body fat from skinfolds or girths in DS and the percent body fat determined by air displacement plethysmography (ADP). Subsequently, Gonzalez-Aguero et al. (2017) and Rossato et al. (2018) developed a DS-specific equation for estimating percent body fat in adolescents and adults (respectively) from surface anthropometry variables using ADP to determine body density. However, the number of subjects used in these studies are small and nonathletes, and whether ADP accurately reflects body fat in these subjects is uncertain.

Whether there is any relationship between body fat levels and a higher incidence of thyroid dysfunction in DS (Hayes and Batshaw 1993) has not yet been determined; however, Allison et al. (1995) reported that the lower resting energy expenditure in DS subjects compared to controls was ameliorated when thyroid function was controlled for. The management of body composition (particularly central adiposity) may be one challenge faced when working with athletes with Down syndrome; however, it is also important to undertake a range of anthropometrical assessments to more fully describe their body composition than just body mass and height and to avoid estimating percent body fat from equations that are not validated in this population.

Undertaking body composition assessments can be more difficult in athletes with intellectual impairments, and practitioners are encouraged to always have another individual with them during the assessment (especially someone familiar to the athlete). Some athletes are not comfortable being touched or are more sensitive to touch, which impacts the ability to undertake surface anthropometry. It can be useful to demonstrate the techniques to the athletes in advance in order to engage them more proactively in the process. Other athletes may be more likely to have difficulty staying still, which makes undertaking DXA scans and ADP more prone to error. It is important for the practitioner and coach to explain the benefits of body composition assessment to the athlete, but also to plan the type and frequency of assessment carefully and develop strategies that optimise the reliability and repeatability of the measurements.

11.4.2 Energy Expenditure

Assessments of resting energy expenditure in athletes with Down syndrome have not been undertaken. There is mixed evidence regarding resting metabolic rates (RMRs) in DS, with some reports indicating reduced RMR in young DS (Luke et al. 1994), whereas others have shown no difference in RMR in a healthy adult DS cohort compared to a control group (Allison et al. 1995; Fernhall et al. 2005). This may be influenced by whether thyroid dysfunction is present and not appropriately managed.

Lante et al. (2010) investigated 31 intellectually impaired individuals (with and without Down syndrome) and found their energy expenditure at various walking speeds to be higher than both a non–intellectually impaired comparison group, and also the typical range of values reported in the "compendium of physical activities" for all but the fastest walking speed (Ainsworth et al. 2011). This is supported by other research in Down syndrome, although the gait instability was found to be greater at higher walking speeds (Agiovlasitis et al. 2011a,b, 2012). Lante et al. (2010) believed the differences were due to uncoordinated and exaggerated gross-motor movements or biomechanical inefficiency in the intellectually impaired group, and this thesis has been supported by other investigations (Ohwada et al. 2005). The use of pedometers or accelerometers to estimate metabolic rate appears to produce greater variability in results for individuals with Down syndrome compared to the general population, so this may not be a valid assessment of exercise energy expenditure (Agiovlasitis et al. 2011a, 2012).

Observing athletes with intellectual impairments in their activities of daily living and general patterns of movement outside of their sport is likely to be important when a practitioner is assessing energy intake guidelines to match estimated energy expenditure.

11.4.3 Clinical Nutrition Needs

Individuals with Down syndrome are at higher risk than the general population of developing Type 1 diabetes (van Goor et al. 1997), coeliac disease (Gale et al. 1997) and thyroid dysfunction (Hayes and Batshaw 1993; Hasanhodzic et al. 2006). The management of diabetes in athletes was discussed in Chapter 10.

Athletes with coeliac disease must follow a strictly gluten-free diet and should be educated regarding suitable choices of carbohydrate-rich foods. Following a gluten-free diet can be more difficult when travelling; however, the availability of gluten-free options is increasing in many countries. It is therefore important for the sports nutrition practitioner to undertake some research and provide the athlete and support staff with a list of items which are suitable to eat in the countries they may be travelling to. Additionally, local coeliac societies will often have information cards translated into a number of different languages to help communicate with caterers regarding the athlete's specific dietary needs.

Thyroid function should be investigated in all athletes with DS since this can influence body composition, bone density and health. Treatment of thyroid dysfunction normally involves medication (such as thyroxine), although some interest has evolved in dietary therapy for treating thyroid dysfunction (Thiel and Fowkes 2007), and there is acknowledgement of increasing levels of iodine deficiency in developed countries. Therefore, the sports nutrition practitioner should actively seek ways to include iodine-containing foods such as seafood and seaweed, dairy foods, eggs, some breads, iodised salt and vegetables grown in iodine-rich soils, in the diet of athletes with DS.

11.4.4 Bone Density

Down syndrome is also associated with an increased incidence of low bone mineral density (BMD) and osteoporosis, independent of gender and height, occurring even in childhood (Angelopoulou et al. 1999; Baptista et al. 2005; Carfi et al. 2017). Although the etiology has not been established, there is evidence for a decrease in bone formation markers compared to control (McKelvey et al. 2012), providing further support for regular exercise in this population. The incidence of low BMD in a free-living DS population has been reported to be as high as 53% (McKelvey et al. 2012). Therefore, it is recommended that athletes with DS be screened for BMD and that all factors related to bone density be optimised, especially when the athlete is still at an age where peak bone mass is being accrued (i.e. <25 y). Nutrition-related factors which optimise bone density include:

i. Adequate vitamin D status (see Chapters 6 and 12).
ii. Adequate calcium intake. Dietary recommendations for calcium intake vary between different countries and at different ages. Since dairy foods

are the best source of calcium and have the added advantage of supporting sports nutrition goals, athletes with DS should be encouraged to consume at least 3–4 servings of dairy foods daily (1000–1300 mg calcium/d). Where the athlete is allergic or intolerant to dairy, appropriate calcium-fortified alternatives (such as calcium-fortified soy milk) and other nondairy sources of calcium (such as fish with edible bones and tofu) should be encouraged before considering calcium supplements.

iii. Adequate vitamin K intake. The research regarding vitamin K and bone health is somewhat limited to date, but indications are that adequate vitamin K is necessary for optimal bone health (Fang et al. 2012). Athletes should be encouraged to consume two or more servings of vegetables rich in vitamin K daily (e.g. broccoli, cabbage, spinach, iceberg lettuce).

11.4.5 Supplements

The nature of some intellectual impairments means that athletes can be heavily influenced by any individual and can therefore be prone to acting on advice which may lead to inappropriate dietary plans or use of supplements. It may be necessary for sporting teams to employ a process of checking athletes personal possessions, especially where they are subject to antidoping testing, in order to ensure any supplements used are appropriate and are low risk for inadvertent doping issues (as outlined in Chapter 14). Checking bags when travelling (especially international travel) to ensure the athlete is compliant with all customs requirements is prudent. Examples of unusual behaviours include:

- A parent sending a child to an international competition with food or supplements without informing team staff.
- Athletes consuming several sports nutrition products, not understanding what they contain or the potential side effects, but not telling anyone because the person who has sold or given them to the athlete has suggested it's best to "keep it a secret." This behaviour could result in an inadvertent failure of antidoping tests.

11.5 PRACTICAL CONSIDERATIONS

Educating athletes with an intellectual impairment can require patience and creativity. Many athletes have short attention spans and by nature of their classification have limitations in their adaptive behaviour, including learning. Education should be undertaken across a number of short-duration sessions, with very precise verbal instructions focussed on one change only, followed up by written information. Generally, messages will require frequent reinforcement. Wherever possible, parents or carers and coaches should be involved in this education in order to facilitate the changes required and ensure reinforcement of messages occurs. Some practical suggestions relating to travel are also included in Chapter 15.

COMMENTARY BOX 11.2

COACH'S INSIGHT: What do you think is the most important thing a sports nutrition practitioner can do to assist your athletes?

> There is a massive need for athletes and coaches to be able to work with sports nutrition practitioners who are both able to impart and reinforce the concepts of "food first" and "food is fuel" (and the practises that accompany them) and adapt standard guidelines and protocols to meet the specific needs of para athletes

Jenni Banks, wheelchair racing and hand cycling coach of 33 years, coach of Paralympic medallists in both sports.

11.6 CONCLUSION AND KEY MESSAGES

Working with athletes with an intellectual impairment requires practitioners to observe them in their home and training environment to best understand their individual behaviours and needs, as well as to develop cohesive communication with their support staff. Practitioners will need to decide on the most critical dietary changes that are required to improve performance and health, and create a strategy to change them progressively. Changes that are required must be communicated succinctly with both the athlete and their support team, with frequent reinforcement.

It is important to screen athletes with Down syndrome for bone density, vitamin D status, thyroid function, coeliac disease and impaired glucose tolerance. Body composition should be assessed using a range of measures and appropriate goals set considering the likelihood of higher body fat levels than able-bodied populations. While formulating a diet to support training needs, the focus should be on ensuring appropriate timing of protein intake postexercise to optimise muscle adaptations to training, and adequate calcium, iodine and vitamin K intakes within an energy budget that is appropriate to their training and body composition requirements.

REFERENCES

Agiovlasitis, S., Motl, R.W., Fahs, C.A. et al. 2011a. Metabolic rate and accelerometer output during walking in people with Down Syndrome. *Medicine and Science in Sports and Exercise* 43:1322–1327.

Agiovlasitis, S., Motl, R.W., Foley, J.T. and Fernhall, B. 2012. Prediction of energy expenditure from wrist accelerometry in people with and without Down syndrome. *Adapted Physical Activity Quarterly* 29:179–190.

Agiovlasitis, S., Motl, R.W., Ranadive, S.M. et al. 2011b. Energetic optimization during overground walking in people with and without Down syndrome. *Gait and Posture* 33:630–634.

Ainsworth, B.E., Haskell, W.L., Herrmann, S.D. et al. 2011. Compendium of physical activities: A second update of codes and MET values. *Medicine and Science in Sports and Exercise* 43:1575–1581.

Allison, D.B., Gomez, J.E., Heshka, S. et al. 1995. Decreased resting metabolic rate among persons with Down Syndrome. *International Journal of Obesity* 19:858–861.

American Psychiatric Association. 2013. *Diagnostic and Statistical Manual of Mental Disorders* (5th edn).

Angelopoulou, N., Souftas, V., Sakadamis, A. and Mandroukas, K. 1999. Bone mineral density in adults with Down's syndrome. *European Radiology* 9:648–651.

Balic, M.G., Mateos, E.C. and Blasco, C.G. 2000. Physical fitness levels of physically active and sedentary adults with Down syndrome. *Adapted Physical Activity Quarterly* 17:310–321.

Baptista, F., Varela, A. and Sardinha, L. 2005. Bone mineral mass in males and females with and without Down syndrome. *Osteoporosis International* 16:380–388.

Barden, H.S. 2003. Growth and development of selected hard tissues in Down syndrome: A review. *Human Biology* 55:539–576.

Boer, P.H. and Moss, S.J. 2016. Effect of continuous aerobic vs. interval training on selected anthropometrical, physiological and functional parameters of adults with Down syndrome. *Journal of Intellectual Disability Research* 60:322–334.

Bronks, R. and Parker, A.W. 1985. Anthropometric observation of adults with Down syndrome. *American Journal of Mental Deficiency* 90:110–113.

Carfi, A., Liperoti, R., Fusco, D. et al. 2017. Bone mineral density in adults with Down syndrome. *Osteoporosis International* 28:2829–2934.

Fang, Y., Hu, C., Tao, X., Wan, Y. and Tao, F. 2012. Effect of vitamin K on bone mineral density: A meta-analysis of randomized control trials. *Journal of Bone Mineral Metabolism* 30:60–68.

Fernhall, B., Figueroa, A., Collier, S., Goulopoulou, S., Giannoploulou, I. and Baynard, T. 2005. Resting metabolic rate is not reduced in obese adults with Down syndrome. *Mental Retardation* 43:391–400.

Fernhall, B. and Pitetti, K.H. 2001. Limitations to physical work capacity in individuals with mental retardation. *Clinical Exercise Physiology* 3:176–185.

Fernhall, B., Pitetti, K.H., Rimmer, J.H. et al. 1996. Cardiorespiratory capacity of individuals with mental retardation including Down syndrome. *Medicine and Science in Sports and Exercise* 28:366–371.

Frey, G.C., McCubbin, J.A., Hannigan-Downs, S., Kasser, S.L. and Skaggs, S.O. 1999. Physical fitness of trained runners with and without mild mental retardation. *Adapted Physical Activity Quarterly* 16:126–137.

Gale, L., Wimalaratna, H., Brotodiharjo, A. and Duggan, J.M. 1997. Down's syndrome is strongly associated with coeliac disease. *Gut* 40:492–496.

Gibson, J.C., Temple, V.A., Anholt, J.P. and Gaul, C.A. 2011. Nutrition needs assessment of young Special Olympics participants. *Journal of Intellectual and Developmental Disability* 36:268–272.

Gonzalez-Aguero, A., Ara, I., Moreno, L.A., Vicente-Rodriguez, G. and Casajus, J.A. 2011. Fat and lean masses in youths with Down syndrome: Gender differences. *Research in Developmental Disabilities* 32:1685–1693.

Gonzalez-Aguero, A., Matute-Llorente, A., Gomez-Cabello, A., Vicente-Rodriguez, G. and Casajus, J.A. 2017. Percentage of body fat in adolescents with Down syndrome: Estimation from skinfolds. *Disability and Health Journal* 10:100–104.

Gonzalez-Aguero, A., Vicente-Rodriguez, G., Moreno, L.A., Guerra-Balic, M., Ara, I. and Casajus, J.A. 2010. Health-related physical fitness in children and adolescents with Down syndrome and response to training. *Scandinavian Journal of Medicine and Science in Sports* 20:716–724.

Hasanhodzic, M., Tahirovic, H. and Lukinac, L. 2006. Down syndrome and thyroid gland. *Bosnian Journal of Basic Medical Sciences* 6:38–42.

Hayes, A. and Batshaw, M.L. 1993. Down syndrome. *Pediatric Clinics of North America* 40:523–535.

Lante, K., Reece, J. and Walkley, J. 2010. Energy expended in adults with and without intellectual disabilities during activities of daily living. *Research in Developmental Disabilities* 31:1380–1389.

Luke, A., Rolzen, N.J., Sutton, M. and Schoeller, D.A. 1994. Energy expenditure in children with Down syndrome: Correcting metabolic rate for movement. *Journal of Pediatrics* 125:829–838.

McKelvey, K.D., Fowler, T.W., Akel, N.S. et al. 2012. Low bone turnover and low bone density in a cohort of adults with Down syndrome. *Osteoporosis International*. doi: 10.1007/s00198-012-2109-4.

Melville, C.A., Cooper, S.A., McGrother, C.W., Thorp, C.F. and Collacott, R. 2005. Obesity in adults with Down syndrome: A case-control study. *Journal of Intellectual Disability Research* 49:125–133.

Ohwada, H., Nakayama, T., Suzuki, Y., Yokoyama, T. and Ishmaru, M. 2005. Energy expenditure in males with mental retardation. *Journal of Nutritional Science and Vitaminology* 51:68–74.

Pitetti, K.H. and Tan, D.M. 1991. Effects of a minimally supervised exercise program for mentally retarded adults. *Medicine and Science in Sports and Exercise* 23:594–601.

Rossato, M., Dellagrana, R.A., da Costa, R.M., Bezerra, E.d., dos Santos, J.O. and Rech, C.R. 2018. The accuracy of anthropometric equations to assess body fat in adults with Down syndrome. *Journal of Applied Research in Intellectual Disabilities* 31:193–199.

Tamse, T.R., Tillman, M.D., Stopka, C.B., Weimer, A.C., Abrams, G.L. and Issa, I.M. 2010. Supervised moderate intensity resistance exercise training improves strength in Special Olympic athletes. *Journal of Strength and Conditioning Research* 24:695–700.

Temple, V.A., Foley, J.T. and Lloyd, M. 2014. Body mass index of adults with intellectual disability participating in Special Olympics by world region. *Journal of Intellectual Disability Research* 58:277–284.

Thiel, R. and Fowkes, S.W. 2007. Down syndrome and thyroid dysfunction: Should nutritional support be the first-line treatment? *Medical Hypotheses* 69:809–815.

Tsimaras, V., Angelopoulou-Sakadami, N., Efstratopoulou, M. and Mandroukas, K. 2001. The influence of a training program on cardiorespiratory capacity of adults with mental retardation. *Exercise and Society* 27:24–31.

Usera, P.C., Foley, J.T. and Yun, J. 2005. Cross-validation of field-based assessments of body composition for individuals with Down syndrome. *Adapted Physical Activity Quarterly* 22:198–206.

Van Biesen, D., Hettinga, F.J., McCulloch, K. and Vanlandewijck, Y.C. 2017. Pacing ability in elite runners with intellectual impairment. *Medicine and Science in Sport and Exercise* 49:588–594.

Van Biesen, D., Jacobs, L., McCulloch, K., Janssens, L. and Vanlandewijck, Y.C. 2018. Cognitive-motor dual-task ability of athletes with and without intellectual impairment. *Journal of Sports Sciences* 36:513–521.

Van de Vliet, P., Rintala, P., Fröjd, K. et al. 2006. Physical fitness profiles of elite athletes with intellectual disability. *Scandinavian Journal of Medicine and Science in Sports* 16:417–425.

Van Goor, J.C., Massa, G.G. and Hirasing, R. 1997. Increased incidence and prevalence of diabetes mellitus in Down's syndrome. *Archives of Disease in Childhood* 77:186 (letters to the editor).

12 Medical Issues, Pharmacology and Nutrient Interaction

Yetsa Tuakli-Wosornu, Nida Naushad, Amos Laar, Christine Townsend and Emerald Lin

CONTENTS

12.1 INTRODUCTION

In both athletes and nonathletes, nutritional status and strategies have wide-reaching functional implications. These range from noncommunicable disease susceptibility to recovery from exercise stimulus (Lenoir-Wijnkoop et al. 2013; Thomas et al. 2016). While all athletes benefit from nutrient-rich diets with adequate calories to support the increased energy and nutrient demands of athletic training (Thomas et al. 2016), for Paralympic athletes, optimising impairment-specific health maintenance, sports performance and recovery may require unique nutritional approaches as outlined in previous chapters. For example, in the setting of swallowing difficulties due to neurological insult or absorption-related nutrient deficiencies causing reduced capacity to ingest adequate calories, athletes may have to use supplements (Maughan et al. 2007). Additionally, Para athletes may take regular medications to manage their condition or its secondary complications, and impairment-related health vulnerabilities can arise in the setting of intense sports participation (Van de Vliet 2012; Webborn and Van de Vliet 2012). Though there is overlap between optimal medical nutrition for various classes of Paralympic athletes, this chapter is primarily organised by impairment type. Taking a holistic approach to athlete health, preventive and therapeutic nutrition should be fully integrated into the medical management of Paralympic sport illness and injury.

12.2 SPINAL CORD INJURY AND CEREBRAL PALSY

12.2.1 Musculoskeletal System

Athletes who have a spinal cord injury (SCI) or cerebral palsy (CP) may experience skeletal muscle atrophy below the level of the neurological lesion (Giangregorio and McCartney 2006; Kern et al. 2017; Verschuren et al. 2018). Decreased muscle mass results in reduced metabolic rates and lower energy expenditures compared to preinjury values. As a consequence, caloric requirements may be reduced (Giangregorio and McCartney 2006). To optimise body weight, health and sports performance, the caloric needs of recreational athletes are likely significantly different from those of elite athletes. High daily training demands and reduced caloric intake may inadvertently lead to macro- and micronutrient deficiencies, negatively impacting body weight, bone health, iron status, oxygen utilisation, immunity, power and injury risk (Scaramella et al. 2018). As outlined in Chapters 6 and 7, Para athletes with SCI or CP may benefit from eating nutrient-dense foods with small frequent feedings to avoid nutritional deficiencies while striking a healthy energy balance and encouraging long-term health. Energy needs may also differ by gender, emphasising the importance of individual nutritional assessment (Goosey-Tolfrey and Crosland 2010).

Low bone density and sublesional, secondary osteoporosis increase the risk of low-energy fracture and other musculoskeletal sequelae in Para athletes with SCI or CP (Giangregorio and McCartney 2006). Bone loss in the paretic limb(s) is particularly striking at the distal femur and proximal tibia and represents a dynamic, rather than an instantaneous, process (Cirnigliaro et al. 2017). Decreasing measurable bone parameters may only approach a new steady state 3–8 years after injury (Eser et al. 2004). Alarmingly, chronic spinally injured athletes with sensory loss may not report pain after sustaining bone fractures; rather, they may complain of spasticity or other nonspecific symptoms, potentially lowering doctors' concern for fracture, delaying an accurate diagnosis and prolonging the injury (Eser et al. 2004).

Factors that may increase the risk of bone fractures include low vitamin D levels, limited weight-bearing activity, decreased energy expenditure and energy intake, anticonvulsant use and limited sun exposure. Sufficient vitamin D (at least 800 IE/d) and calcium (at least 1000 mg/d) intake may help decrease the risk of bone fracture (Frotzler et al. 2009). Natural sources of vitamin D include salmon, cod liver oil, tuna, cheese and butter; calcium-rich foods include dairy products, tofu and fish with soft bones (Scaramella et al. 2018). Unfortunately, studies of SCI athletes show an inability to consume sufficient dietary vitamin D to maintain adequate vitamin D status; hence, vitamin D supplementation is recommended when plasma vitamin D status is shown to be suboptimal (Scaramella et al. 2018). Evidence suggests that a sliding scale dose of vitamin D supplement based on plasma vitamin D status (see Table 12.1) is effective in returning most individuals to normal levels within 16 weeks (Pritchett et al. 2018) and should be considered in situations where regular sunlight exposure is limited. Supplementation with vitamin D is not recommended when current vitamin D status is unknown since high vitamin D doses and plasma concentrations can induce toxicity (Owens et al. 2018). A calcium-rich, pre-exercise meal may be protective of bone for those undertaking a high-intensity training session (Haakonssen et al. 2015). Severe bone loss is treated with bisphosphonates (Zehnder et al. 2004); however, bisphosphonates have low bioavailability, so to optimise absorption, athletes taking bisphosphonates should aim to ingest them 30 minutes before breakfast, with only water (Porras et al. 1999).

Standard muscle spasticity treatment for athletes with SCI often includes myotonolytic medications, such as Baclofen or Tizanidine (Kheder and Nair 2012).

TABLE 12.1
Vitamin D Supplementation Recommendations for Adults

Vitamin D Status	Supplementation	Duration	Maintenance
$\leq$20 ng/mL (<50 nmol/mL)	50,000 IU/wk	8 weeks	1500–3000 IU/d
21–30 ng/mL (50–75 nmol/mL)	35,000 IU/wk or 4000–5000 IU/d	8 weeks	1500–2000 IU/d
30–40 ng/mL (75–100 nmol/mL)	2000–4000 IU/d		1500–2000 IU/d

Source: Adapted from Scaramella, J. et al. 2018. *Physical Medicine and Rehabilitation Clinics of North America* 29:283–298; Pritchett, K. et al. 2018. *International Journal of Sport Nutrition and Exercise Metabolism* 14:1–23.

A subset of athletes use chronic Baclofen delivered via medication pump (Van de Vliet 2012). Myotonolytic medications act centrally; athletes using these medications are advised to refrain from alcohol consumption, which may intensify central side effects (e.g., nausea, somnolence, impaired cognition; Kheder and Nair 2012). Pre-existing spasticity can also be exacerbated by extramuscular factors, including constipation, urinary tract infections and deep tissue injuries. Optimising hydration may be a simple, accessible nutritional approach to minimising spasticity due to external, nonmusculoskeletal organ systems (Kheder and Nair 2012).

12.2.2 Integumentary System

Deep tissues injuries (DTIs), or pressure wounds, are among the most common, debilitating and frustrating injuries for seated Para athletes, and prevention is critical (Berthold et al. 2013; Shimizu et al. 2017). Well-documented risk factors for DTI in athletes and nonathletes with SCI include lack of sensation, mobility limitations, moisture from varying levels of bowel and/or bladder incontinence and muscle atrophy (Groah et al. 2015). Helpful measures include blood screening for metabolic deficiencies (e.g., albumin, prealbumin, zinc, ferritin, vitamin B12, folic acid, haemoglobin), careful examination of skin, keeping skin dry and clean and regular pressure relief (Cruse et al. 2000). Nutrition-based prevention strategies include limiting alcohol consumption and consuming a well-balanced diet with regular weight monitoring (Regan et al. 2009). If an athlete is recovering from DTI, their total energy intake and protein needs are increased; thus, optimal caloric intake is essential. The Agency for Healthcare Research and Quality recommends that patients with pressure ulcers consume 1.25–1.5 g/kg protein daily (Dorner et al. 2009). In the setting of integumentary disease, supplemental amino acids such as arginine and glutamine, in combination with fish oils, have been successfully used as part of a holistic wound-healing strategy (Alexander and Supp 2014; Shepherd 2003). Beyond energy and protein, micronutrients such as zinc and vitamin C have been shown to help skin repair, integrity and preservation in conjunction with optimal hydration (Saghaleini et al. 2018). Zinc is an antioxidant that is also involved in collagen formation and protein synthesis. Zinc deficiency can cause poor wound healing as well as loss of appetite, abnormal taste and impaired immune function. The daily recommended intake of zinc is 6.8 and 9.4 mg for adult females and males, respectively. It is not recommended to supplement zinc unless a deficiency is suspected, and the maximum recommended supplementation in zinc deficiency is 40 mg of elemental zinc per day (Institute of Medicine 2018). Vitamin C is a cofactor involved in the production of collagen and is therefore thought to be important for tissue repair and regeneration; however, larger doses of vitamin C have not been shown to be more effective than lower doses (ter Riet et al. 1995). The daily recommended intake of vitamin C is 75–90 mg.

12.2.3 Central Nervous System

Para athletes who are spinally injured at thoracic level 6 or above may experience autonomic dysreflexia (AD), a potentially life-threatening condition caused by abnormal, unopposed sympathetic outflow following a noxious stimulus below the level of the spinal injury. AD is a medical emergency, which can result in hypertension, bradycardia, headache, nasal congestion, chills, goose bumps and blurred vision (Cowan 2015; Van de Vliet 2012). Noxious stimuli that trigger AD include bladder distension, urinary tract infection, bowel distension (e.g., due to constipation), skin lesion/injury or increased intra-abdominal pressure (e.g., in the setting of tight-fitting garments; Krassioukov 2012). While dangerous, AD can provide an objective performance advantage (Krassioukov 2012; Walter and Krassioukov 2018); thus, athletes may intentionally try to trigger AD by various means including not emptying their bladders, tapping on full bladders or applying tourniquet-like strictures to the lower extremities. The intentional induction of AD to achieve a competitive advantage is called "boosting," and is strictly prohibited in Paralympic competition but still happens in competitive and recreational para competition, which poses a health risk to these athletes (Bhambhani et al. 2010; Mazzeo et al. 2015; Walter and Krassioukov 2018). AD treatment includes removing noxious stimuli, monitoring symptoms and potentially treating any resulting hypertension. Avoiding triggers is essential for prevention and, from a nutritional standpoint, adequate fluid intake with intermittent catheterisation is important for optimal bladder health (Christison et al. 2018; Spinu et al. 2012). Furthermore, hydration, a high-fibre diet and potentially the use of laxatives can help maintain good bowel health (Tate et al. 2016; see musculoskeletal section above and gastrointestinal and genitourinary section below for more details).

Para athletes with SCI may have difficulty with thermoregulation during exercise (Price 2006). The location of the spinal cord lesion may affect the degree of thermodysregulation. Athletes with thoracic or lumbar spinal lesions have increased risk of heat injury in warm conditions (25–40°C) due to increased heat storage in the lower body and decreased whole-body sweat rates. Athletes with cervical lesions may experience difficulty with thermoregulation in both warm and cool environments due to decreased sympathetic outflow leading to reduced or absent sweating. Thermoregulatory control strategies are outlined in Chapter 5.

12.2.4 Gastrointestinal and Genitourinary Systems

People with SCI may experience bladder dysfunction depending on the level, duration and severity of their spinal cord lesion (Cruz and Cruz 2011). For example, lesions of the cervical and thoracic spinal cord may lead to areflexia, urinary retention and bladder hypertrophy due to dyscoordination of some muscles of the urinary bladder and urethra (detrusor-sphincter dyssynergia; Hansen et al. 2010). Standard treatments include continuous implantation of catheters and bladder stimulants that can increase the risk of a urinary tract infection (UTI; Jahromi et al. 2014). Frequent fluid intake may help prevent UTIs, though the data regarding this is mixed (Lotan et al. 2013). If not using indwelling catheters, which are the preferred method as they are associated with reduced incident of urological complication (Everaert et al. 2009), frequent bladder emptying, such as by intermittent catheterisation, should occur every 4–6 hours (Consortium for Spinal Cord Medicine 2006). Athletes sometimes choose to dehydrate when travelling because of the inconvenience of frequent bladder emptying, but this increases UTI risk. Adequate hydration is recommended during travelling. Strategies such as placement of catheterisation equipment in hand luggage and seating preferences that allow access to toilet facilities are recommended (Compton et al. 2015). If this is infeasible, athletes may also consider discussing antibiotic prophylaxis with their healthcare provider (Compton et al. 2015). Several nutrients have been investigated due to their potential prophylactic role in reducing the incidence of UTI, including cranberries (especially dried and extract capsules), probiotics and D-mannose (Beerepoot and Geerlings 2016; Pannek and Wollner 2017). Results to date are mixed, and benefits may vary between individuals depending on the primary cause of the UTI. Further work in this area should be done since consistent use of antibiotic prophylaxis can result in antibiotic resistance (Pannek and Wollner 2017).

Antibiotics are the current standard of care for UTIs, but key nutritional parameters are needed to maximise effectiveness. Several antibiotics, such as tetracycline, ciprofloxacin, norfloxacin and ofloxacin, build insoluble complexes with iron and zinc, leading to reduced absorption of both the antibiotic and the mineral consumed in food or nutritional supplements (Furedi et al. 2009; Lehto et al. 1994; Polk et al. 1989) – thus, the antibiotic dose should be taken at least 2 hours apart from iron or zinc supplements or food intake (Mason 2010). More specifically, ingestion of tetracyclines with milk should be avoided because doing so decreases its absorption and effectiveness (Papai et al. 2010).

People with a SCI may experience bowel dysfunction such as faecal incontinence and constipation (Glickman and Kamm 1996), and dietary manipulation is critical in the management of bowel dysfunction. Adequate water intake helps soften stool, and fibre gives stool bulk and plasticity (Lynch et al. 2001). Any change in dietary fibre intake should be undertaken gradually in order to prevent side effects.

Erectile dysfunction is common among males with SCI, with 75% of males with SCI reporting they have erectile dysfunction (Stone 1987). Currently, selective phosphodiesterase inhibitors, like sildenafil, are a common treatment for erectile dysfunction. Nutritionally, grapefruit juice and foods rich in nitrates like beetroot or spinach juice should be avoided if taking sildenafil (Ishikura et al. 2000; Jetter et al. 2002; Kloner et al. 2003).

12.3 VISION AND AUDITORY IMPAIRMENT

12.3.1 Musculoskeletal System

Chronic overuse injuries in bone, tendon, skeletal muscle and other soft tissue (i.e. strains, sprains, spasms) are more common than acute traumatic musculoskeletal injuries in athletes with vision and auditory impairment (Magno e Silva et al. 2013a,b; Tuakli-Wosornu et al. 2018). In addition to the regular wear and tear associated with high-level athletic training among athletes with vision impairment, poor proprioception can result in abnormal gait patterns during daily ambulation, which can predispose overuse injuries of the lower weight-bearing extremities (Klenck and Gebke 2007). However, elite hearing-impaired athletes do not seem to suffer from proprioceptive imbalances (Nakajima et al. 2012).

Paralympians with vision or auditory impairment recover from musculoskeletal injuries in the same way that sighted Olympians do. Adequate energy intake, an optimal protein balance and the ingestion of essential fatty acids (i.e. Omega 3 fatty acids) and antioxidants may improve muscle, skin/tendon and bone healing (Domazetovic et al. 2017; Poortmans et al. 2012). If the injury warrants immobilisation, increased protein intake (1.6–2.5 g/kg/day) is necessary to minimise muscle atrophy (Wall et al. 2015).

12.4 AMPUTEE AND OTHER PHYSICAL IMPAIRMENTS

Athletes with an amputation have experienced partial or total absence/loss of bones or joints in the upper or lower extremities as the result of congenital or acquired medical condition(s) (Grobler and Derman 2018). Congenital amputations are birth anomalies, while acquired amputations may result from trauma (e.g., a motor vehicle accident) or lifestyle-related disease (e.g., diabetes mellitus, dysvascular disease). The minimum eligibility criteria for participation in a classified Paralympic sport include amputation at least through the wrist for upper-extremity amputees and at least through the ankle for lower-extremity amputees. Limb loss and/or prosthetic use place amputee athletes at increased risk of unique illnesses and injuries described below (Chapter 8; Grobler and Derman 2018).

Para athletes with other physical impairments are challenging to summarise because of their diverse diagnoses, including rare syndromes with anomalies in different body systems. These athletes may have nerve injury resulting in local paralysis (such as with a diagnosis of multiple sclerosis), spondyloepiphyseal dysplasia causing neurological dysfunction, Becker muscular dystrophy (which may be associated with cardiac pathology), nonspinal poliomyelitis, ankylosis, leg shortening, joint movement restriction and other medical conditions that do not fall neatly into alternative impairment types (Chapter 9; Webborn and Van de Vliet 2012).

12.4.1 Musculoskeletal System

Amputee athletes incur varying levels of risk for musculoskeletal injury depending on prosthetic use, potential for malignancy and continued dysvacular risk. Upper-extremity amputees infrequently use sport-specific prostheses during competition. For example, Para cyclists may rely on upper-extremity prostheses purely for steering and gear changes (Bragaru et al. 2012). In contrast, lower-extremity amputees frequently don sport-specific leg prostheses for land-based sport only, the technological components of which vary based on the demands of the sport, athlete skill level, athlete comfort and extent of amputation (Grobler and Derman 2018).

General trends in musculoskeletal injury patterns and rates seem to be similar among amputee and able-bodied athletes in the same sport, with minor overuse tendinopathies and other musculoskeletal injuries being most common (Fagher and Lexell 2014; Klenck and Gebke 2007; Tuakli-Wosornu et al. 2018; Webborn and Emery 2014). Nutrients such as proteins, amino acids (leucine, arginine, glutamine), vitamins C and D, manganese, copper, zinc and phytochemicals may be useful in aiding tendon growth, strengthening and healing (Curtis 2016). Of particular interest are scientists' recent attempts to leverage nutrient combinations to achieve greater effects on collagen. For example, Shaw et al. (2017) conducted a randomised, controlled trial demonstrating that vitamin C-enriched gelatine supplementation, given 1 hour before intermittent bouts of exercise that stimulate collagen synthesis (6 minutes of rope skipping) increased circulating glycine, proline, hydroxyproline and hydroxylysine in health subjects in a dose-dependent manner. Furthermore, engineered ligaments demonstrated increased collagen content and improved mechanics *in vitro* when treated with the serum of subjects who ingested gelatine, as compared to those who ingested placebo solution; again, a dose-response was observed (Shaw et al. 2017). While results are promising, further work is required to determine optimal strategies to incorporate such dietary interventions into day-to-day training routines compared to recovery from injury.

For athletes who have experienced amputation due to musculoskeletal malignancy, malignancy recurrence remains a risk (Barr and Wunder 2009; Puhaindran et al. 2012). Regular medical screenings at appropriate time intervals, in addition to having an antioxidant-rich diet, may be part of a holistic preventive strategy.

For the dysvascular amputee, contralateral limb amputation is a risk (Glaser et al. 2013). A healthy diet emphasising optimal hydration and whole, nutrient-rich, cardioprotective foods (e.g., fish oils, yoghurt, colourful fruits and vegetables), while minimising highly processed foods, excess sugars and saturated fats can help combat the biochemical and cardiometabolic imbalances that predispose athletes to contralateral limb amputation (Fernandez et al. 2017; Salas-Salvado et al. 2018; Sears 2015).

12.4.2 Central Nervous System

Athletes with an amputation can be at increased risk of temperature dysregulation, including heat illness, and hypothermia due to reduced body surface area (Grobler and Derman 2018). Widespread microvascular disease may predispose the dysvascular amputee athlete to metabolically mediated thermal dysregulation due to the inability to vasodilate appropriately (Grobler and Derman 2018). In addition, prosthetic users may perceive thermal discomfort at the residual limb-prosthetic interface (usually, perceived warming during physical activity and perceived cooling during rest), whether or not there are significant changes in skin temperature (Segal and Klute 2016). Discussion on thermoregulatory management strategies can be found in Chapter 5.

Athletes with multiple sclerosis can experience chronic fatigue syndrome and increased core temperatures, which can be addressed through proper sleep hygiene, adequate caloric intake and thermoregulatory strategies, as outlined in Chapter 5.

Up to 80% of persons with lower-extremity amputation will experience chronic neuropathic or nociceptive pain globally due to dysregulated neural tissues and/or inflammation. Phantom limb pain is defined as neuropathic pain experienced in the missing limb(s), which is distinct from stump pain, defined as nociceptive pain experienced at the distal residual limb (Grobler et al. 2018; Siddiqui et al. 2014). Topical anticonvulsant and anti-inflammatory medications, opioids and, rarely, an additional amputation proximal to the original level can help, while mindfulness, cognitive behavioural therapy, mirror therapy and desensitisation play important roles (Alviar et al. 2016). Preliminary analyses suggest that effective nutritional strategies may include consuming a more anti-inflammatory and antioxidant-rich diet, emphasising carbohydrates with low glycaemic index, fruits and vegetables, yoghurt and olive oil; minimising red or processed meats and potentially supplementing with vitamin B12, vitamin D, omega-3 fatty acids and fibre (Rondanelli et al. 2018), all of which are encompassed by the dietary recommendations for athletes. Beyond biology, the pain experience of athletes is influenced by psychological and contextual domains (Alviar et al. 2016; Grobler et al. 2018; Hainline et al. 2017); thus, nonpharmacologic prevention and treatment approaches, including behavioural and nutritional, are particularly apt.

12.4.3 Integumentary System

Athletes who wear lower-extremity prostheses can experience stump infections, abrasions, ulcers and DTIs due to skin chafing, excessive sweating and both compressive and shear forces on skin that is poorly adapted to load-bearing (Hagberg and Branemark 2001). "Choke syndrome" results from impaired venous return and increased lymphatic and venous pooling in soft tissues in and around the residual limb. Use of prostheses with a well-fitting, silicone-lined socket, good skin hygiene (e.g., talcum powders, cool clothing, regular skin drying) and regular skin checks can help prevent/reduce soft tissue damage (Hagberg and Branemark 2001). Foods and supplements known to encourage healthy vascular circulation and optimise collagen health may also be beneficial. These include vegetables and fruits (Boeing et al. 2012), curcumin (Santos-Parker et al. 2017) and vitamin C (potentially in combination with other supplements, as above; Shaw et al. 2017). As outlined in Section 12.2.2, amputee athletes recovering from DTI may benefit from specific nutrient supplementation.

12.5 TRAUMATIC BRAIN INJURY

Athletes who have suffered a traumatic brain injury (TBI) may have multiple sequelae of the injury. Cognitive deficits are a common complication of traumatic brain injury, while many other potential medical issues including posttraumatic epilepsy, chronic kidney disease, wounds related to acute trauma and pressure ulcers can also occur (Wu et al. 2017). It is likely that the increased organ and system involvement is due to a number of factors, including energy expenditure shunted towards recovery, altered system and organ networks and immobility (Zygun et al. 2005). The use of nutraceuticals in addition to traditional medicine for these complications is an active and developing area of research. In this section, we will discuss some of the vitamins, minerals, diets and supplements that have shown some potential benefits for specific medical issues in traumatic brain injury models. It is important to highlight that most of these have been shown to be beneficial following acute injury (such as concussion) as opposed to chronic injury (such as acquired brain injury, as outlined in Chapter 7).

12.5.1 Central Nervous System

One of the major central nervous system (CNS) effects of traumatic brain injury is cognitive deficits. The brain is approximately 60% lipid by weight (Bazinet and Laye 2014). The three most important omega-3 fatty acids are docosahexaenoic acid

(DHA), eicosapentaenoic acid (EPA) and alpha-linolenic acid (ALA), with DHA being the most abundant fatty acid in the cerebral cortex of mammals (Bazinet and Laye 2014). Omega-3 fatty acids are flexible structures and are vital for their ability to alter membrane activity, structure, fluidity and ion permeability in the brain. Additionally, they contribute many anti-inflammatory effects (Laye et al. 2018). Multiple animal studies have shown DHA to be neuroprotective and to ameliorate secondary mechanisms of injury when given prior to traumatic brain injury in rats, as well as showing cognitive improvement and tissue sparing when administered after traumatic brain injury (Hasadsri et al. 2013; Schober et al. 2016). It has also been shown that DHA-deficient mice have impaired functional recovery after traumatic brain injury (Desai et al. 2014). However, there is little clinical evidence supporting the use of omega-3 fatty acids in traumatic brain injury in humans and more studies are needed. In one case report involving a teenager who suffered a severe traumatic brain injury and was believed to be in a persistent vegetative state, 30 mL/day of an omega-3 fatty acid supplement (19,212 mg total) was started on day 10 after injury. Consequently, the patient was weaned off the ventilator on day 21 with improvement in behavioural and cognitive function. Over the course of 2 years, he went from being completely dependent and responding inconsistently to simple commands to requiring only standby assistance with daily living skills and being capable of learning new tasks (Lewis et al. 2013). Given the relative safety of omega-3 fatty acids and their known benefit in cardiovascular health, it seems reasonable to suggest supplementation in traumatic brain injury populations and athletes at increased risk for repeat mild head trauma (e.g., concussions).

ALA is an essential fatty acid and is a precursor to DHA and EPA. However, the conversion of ALA to DHA and EPA is minimal, so DHA and EPA should also be consumed directly in the diet (Sun et al. 2017). Sources of ALA include green plants, nuts, flaxseed and grapeseed oil. Sources of EPA and DHA are primarily oily fish such as tuna, anchovies, salmon, halibut and algae. Since ALA is the only fatty acid that is considered essential, it is the only omega-3 fatty acid that the National Academy of Medicine has established adequate intake (AI) recommendations for. For healthy adults, the AI of ALA is 1.1–1.6 g daily for women and men, respectively (Institute of Medicine 2005). The Food and Drug Administration (FDA) has confirmed the overall safety of fish oil, both DHA and EPA, at levels up to 3 g/day.

Branched chain amino acids (BCAAs) are key amino acids involved in the synthesis of the neurotransmitters glutamate and gaba-amino butyric acid (Sakai et al. 2004). One study showed that mice had significantly decreased levels of valine, isoleucine and leucine in the hippocampus 7 days after a lateral fluid percussion injury. These mice also demonstrated significant cognitive impairment based on conditioned fear response. Dietary replacement with 100 mM each of valine, isoleucine and leucine for 5 days restored the hippocampal BCAA levels to baseline as well as restoring cognitive function (Cole et al. 2010). Foods that are rich in BCAAs include milk proteins, beef, chicken, fish and eggs; however, it is unlikely an athlete consuming sufficient dietary protein will be low in BCAA.

Other nutraceutical options that have been investigated for their potential neuroprotective effects for pre- or post-traumatic brain injury are curcumin;

resveratrol; creatine and vitamins C, D and E, among many others (Petraglia et al. 2011). In laboratory studies, curcumin has shown anti-inflammatory and antioxidant properties, and a derivative of curcumin, CNB-001, has been shown to prevent reductions in proteins that are important for learning, memory and synaptic transmission (Sharma et al. 2010). In one study looking at mouse models of traumatic brain injury, administration of curcumin prior to injury significantly attenuated cerebral oedema and decreased expression of glial fibrillary protein, which is a reactive astrocyte marker after injury (Laird et al. 2010). Resveratrol is a naturally occurring compound found in red wine, grapes and peanuts, that has been shown to have antioxidant properties as well as reducing post-traumatic neuronal loss, improving behavioural measures of locomotion, anxiety and novel object recognition memory in rodents (Sonmez et al. 2007). Creatine has been studied in acute traumatic brain injury in children and adolescents up to 6 months postinjury and was shown to improve indices of cognition, personality and behaviour, self-care and communication abilities (Sakellaris et al. 2006). Vitamins C and E are known antioxidants, and it has been speculated that combined vitamin C and E therapy acts synergistically in neuroprotection (Petraglia et al. 2011). Vitamin D has been shown to enhance neuroprotection when given in combination with progesterone, compared to progesterone alone *in vitro* (Atif et al. 2009). However, all of these have limited human studies to provide strong evidence for or against the use of nutraceuticals in the treatment of chronic brain injury. Daily recommended intake of vitamin D is 600–800 IU, vitamin C is 75–90 mg and vitamin E is 15 mg in healthy adults. Curcumin, resveratrol and creatine do not have daily recommended intake values. All these values may vary greatly in athletes with a TBI, but currently there remains a paucity of research for this population; therefore, the primary recommendation is a nutrient-dense diet rich in antioxidant foods, which is already part of the recommendations for athletes.

Another CNS-related issue in patients with chronic traumatic brain injury is post-traumatic epilepsy. The primary energy source in the brain is glucose, and in the absence of glucose, ketones are used. Low-carbohydrate diets such as the ketogenic or modified Atkins diets have been established as an alternative form of treatment in patients with epilepsy refractory to medications. Paediatric studies and more recently adult studies have shown trends towards decreasing the frequency of seizures in about 50% of patients refractory to medication (Cervenka et al. 2017; Nei et al. 2014). One drawback of these diets is difficulty with compliance in the adult population. Adverse effects must also be considered, as studies have shown increased blood lipid levels; unintentional weight loss; amenorrhea in women and gastrointestinal side effects such as nausea, vomiting, diarrhoea or constipation (Pasca et al. 2016). Furthermore, a ketogenic diet may not be compatible with the fuelling requirements of the athlete. The health and safety of the athlete must always be a sports nutrition practitioner's primary focus; therefore, working with the athlete and neurologist to find a compromise that minimises seizures whilst still supporting training and competition needs is paramount. It is important to note, these studies have only looked at post-traumatic epilepsy and therefore may not be fully applicable to the traumatic brain injury population.

12.5.2 Gastrointestinal and Genitourinary Systems

Individuals who suffer from traumatic brain injury are also at a slightly increased risk for developing chronic kidney disease (CKD) compared to the general population, possibly due to short- and long-term deleterious effects of acute brain injury (e.g., increased inflammation, exaggerated sympathetic nervous system activity leading to reduced renal perfusion) as well as other risk factors of CKD such as increased nonsteroidal anti-inflammatory medication (NSAID) use (Wu et al. 2017). Recent studies have suggested use of prebiotic and probiotic treatments may ameliorate kidney function. One study showed significant improvement in serum blood urea nitrogen and creatinine in rat models of CKD who were fed diets including the prebiotics glutamine, dietary fibre, an oligosaccharide and the probiotic *Bifidobacterium longum* compared to a control diet which did not contain prebiotics or probiotics (Iwashita et al. 2018). The FDA recommendations for fibre intake are 25 g per day for a 8400 kJ (2000 kcal) diet. There are not established recommended daily values for glutamine, oligosaccharide or probiotics. High-protein diets may accelerate the progression of chronic kidney disease. The current recommendation for protein intake for adults with chronic kidney disease is 0.8 g/kg per day, and it is recommended to avoid >1.3 g/kg per day (KDIGO 2013). Both the athlete and their healthcare team must be aware of their slightly increased risk of kidney disease, as this can affect the medications they take, hydration and training status.

12.5.3 Integumentary System

After an acute traumatic brain injury, there are often concurrent skin wounds and the potential for pressure ulcers. This is likely due to a number of reasons, including decreased mobility and inadequate compensation for increased nutrition requirements. There are also increased protein requirements to promote healing in patients with open wounds. Refer to Section 12.2.2 for more information regarding nutrition and pressure ulcers.

12.6 PHARMACOLOGY AND NUTRIENT INTERACTIONS

It is the responsibility of the sports physician to undertake a full medical evaluation of an athlete, including their medications, with respect to both clinical need and World Anti-Doping Guidelines. If the need for regulated medication is significant, an application may be made for a Therapeutic Use Exemption from the International Paralympic Committee (Grobler and Derman 2018). Athletes and coaches not only have to be aware of the current antidoping regulations, but also that drugs may interact with food and supplement intake (McDowall 2007). Unfortunately, the public health relevance of nutrient-drug interactions is generally undervalued and overlooked. This is particularly true for athletes with impairments where multimorbidity and polypharmacy may be a norm. Vitamins and other micronutrients have central functions in metabolism, and their interactions with medically necessary drugs may result in clinically relevant physiological impairments or positive effects. Interactions can involve single or multiple nutrient(s), food in general and/or nutrition status

(Boullata and Hudson 2012). Most of the known nutrient-drug interactions involve changes in oral bioavailability and absorption of the drug. Nutrient-drug interactions may occur because of altered intestinal transport, metabolism and excretion of the interacting substances or problems with the systemic distribution (Boullata and Hudson 2012; McDowall 2007). Such interactions are based on changes in pharmacokinetic, pharmacodynamic and pharmaceutical properties (Boullata and Hudson 2012; Bushra et al. 2011). Discussed below and summarised in Table 12.2 are some examples of commonly used drugs in Para sports and possible nutritional interactions.

12.6.1 Antacids

Antacids reduce and/or neutralise gastric acidity, making them useful medications for gastric reflux, indigestion and heartburn. Antacids have different classes (e.g., H2-antihistamines, proton pump inhibitors) with specific pharmacological mechanisms. However, independent of the pharmacological mechanism, vitamin B12 release from dietary proteins is decreased due to the lack of gastric acid, which may lead to a vitamin B12 undersupply with chronic use of antacids (Ruscin et al. 2002). Vitamin B12 plays a crucial role in the health of the body's nerve and blood cells, DNA synthesis and prevention of megaloblastic anaemia, which leads to weakness and fatigue (Office of Dietary Supplements 2011). The bioavailability of omeprazole, a proton pump inhibitor, seems to be increased by soybean administration, whereas esomeprazole, another proton pump inhibitor, showed a significantly decreased bioavailability when taken 15 minutes before eating a high-fat meal compared to the fasted state (Singh and Asad 2010; Sostek et al. 2007).

12.6.2 Antibiotics

Antibiotics are substances prescribed to treat bacterial infections, which often affect the respiratory system or urinary tract of athletes with an impairment. Some antibiotics build insoluble complexes with iron and zinc which can lead to a reduced absorption of the drug and the mineral, as found in food or a supplement, as well (Furedi et al. 2009; Lehto et al. 1994; Polk et al. 1989). To avoid such interactions, the intake of antibiotics should be separated at least 2 hours from iron or zinc supplement or food intake (Mason 2010).

12.6.3 Anticholinergics

Anticholinergics (e.g., oxybutynin, solifenacin, fesoterodine) block muscarinic receptors in both the central and peripheral nervous system, thus reducing the effect of acetylcholine. This reduction relaxes the smooth muscles of the bladder and renal tract. Anticholinergics are often applied to treat the symptoms of the neurogenic bladder in athletes with a spinal cord injury (Madhuvrata et al. 2012). A recently published study showed no clinically relevant difference between the ingestion of fesoterodine in a fasted state or after a high-fat, high-caloric meal (Malhotra et al. 2009). This supports the hypothesis that anticholinergics can be administered regardless of food intake.

TABLE 12.2
Known Drugs, Their Functions and Pertinent Nutrient Interactions

Drug Name	Brand Name	Function/Drug Class	Pertinent Nutrient Interactions
Acetaminophen	Tylenol	Analgesic	Absorption may be decreased when given with food
Amitriptyline hydrochloride	Tryptanol	Antidepressant	Many drug interactions, check with healthcare provider prior to use
Azithromycin	Zithromax	Antibiotic, macrolide	Take extended-release suspension on an empty stomach
Carbamazepine	Tegretol	Mood stabiliser, anticonvulsant	Avoid concurrent ingestion of grapefruit juice, maintain adequate hydration
Cephalexin	Keflex	Antibiotic, cephalosporin	Avoid multivitamin $\geq$3 hrs after cephalexin (Zn may decrease absorption)
Cranberry juice or tablets		Bladder control/ antiseptics	>3–4 L per day may lead to diarrhoea
Cyclobenzaprine	Flexeril	Muscle relaxer	Food increases bioavailability (monitor effects)
Diazepam	Valium	Muscle relaxer, antianxiety	Avoid concurrent use of grapefruit juice. May enhance CNS depressant effect of alcohol
Dihydrocodine	Hysingla, Zohydro	Opioid analgesic	May enhance CNS depressant effect of alcohol; avoid alcohol with extended release form
Enemas	Bisalax, Bisacodyl	Laxative	Take on empty stomach, don't take within 1 hr of dairy
Hydrocodone	Hysingla, Zohydro	Opioid analgesic, antitussive	May enhance CNS depressant effect of alcohol; avoid alcohol with extended release form
Ibuprofen	Advil	NSAID, pain reliever	Administer with food to avoid ulcers
Naproxen	Aleve	NSAID, pain reliever	Administer with food, milk or antacids to decrease GI adverse effects
Nitrofurantoin	Furadantin, Macrobid, Macrodantin	Antibiotic (UTI treatment)	Administer with meals
Omeprazole	Prilosec	GERD (PPI), ulcer treatment, antisecretory	Prolonged treatment ($\geq$2 years) may lead to malabsorption of vitamin B12 & deficiency

(*Continued*)

TABLE 12.2 (*Continued*)
Known Drugs, Their Functions and Pertinent Nutrient Interactions

Drug Name	Brand Name	Function/Drug Class	Pertinent Nutrient Interactions
Phenobarbitone	Phenobarbital	Muscle relaxer, anticonvulsant, barbiturate	May cause decrease in vitamin D and calcium (supplement & increase food sources)
Psyllium	Metamucil	Dietary fibre laxative, bulk forming	Take with water; abdominal cramps
Ranitidine	Zantac	Antiulcer, antihistamine	Prolonged treatment (≥2 years) may lead to malabsorption of vitamin B12 & deficiency
Trazodone	Oleptro	Antidepressant	Give immediate release after meals to decrease light-headedness & postural hypotension. Give extended release on an empty stomach
Vardenafil	Levitra	Erectile dysfunction	Do not take with a high-fat meal, & avoid grapefruit juice
Zolpidem	Ambien	Sedative (for insomnia), hypnotic	Do not administer with (or immediately after) a meal & avoid grapefruit juice

12.6.4 Anticoagulants

Warfarin is a common anticoagulant used to influence the coagulation of blood. Vitamin K plays an important role in blood coagulation; therefore, ingestion of large amounts of vegetables rich in vitamin K (e.g., broccoli) or dietary supplements containing Vitamin K can interfere with the effectiveness and safety of warfarin intake. Warfarin has also been reported to interact with other foods such as cooked onions, cranberry juice, char-grilled food or a high-protein diet (Bushra et al. 2011).

12.6.5 Bisphosphonates

The acquisition and maintenance of bone mass and strength are influenced by physical activity and nutrition (Bonjour 2011). Severe bone loss is a major problem in persons with spinal cord injury, substantial muscle atrophy, lower-limb amputees and others who experience reduced loading on bone; it is treated with bisphosphonates such as alendronate (Eser et al. 2004). Due to the low bioavailability of this substance class, the ingestion 30 minutes before breakfast with water only is recommended to optimise absorption (Porras et al. 1999).

12.6.6 Bronchodilators

Theophylline is a xanthine derivate which induces bronchodilation. The drug is used for asthma treatment, and its bioavailability is influenced by high-fat (increased bioavailability) or high-carbohydrate meals (decreased bioavailability). The ingestion of alcohol with theophylline may increase side effects such as nausea or vomiting. Additionally, caffeine belongs also to the group of xanthine derivatives, so ingestion of food and drink containing caffeine with theophylline may increase drug toxicity (Bushra et al. 2011).

12.6.7 Herbal Products

Due to the growing use of herbal products or supplements such as ginseng, garlic, valerian, gingko, Echinacea or St. John's wort, coaches and athletes need to know whether problems arise when using these with conventional drugs (Chavez et al. 2006; Peng et al. 2004). Herbal products are vigorously marketed to both competitive and recreational athletes with claims of performance gains and improved health and wellness (Winterstein and Storrs 2001). Though these substances are of natural origin, it does not automatically mean that they are harmless or that no such interactions exist. In fact, the effect of a drug can significantly change as transporters and enzymes are influenced by the consumption of herbal supplements and can induce severe side effects (Bilgi et al. 2010; Peng et al. 2004). Furthermore, these supplements may result in a positive doping test, as they may contain banned substances without showing them on their label (de Hon and Coumans 2007).

St. John's wort, a common herbal product used to treat mild to moderate depression, shows a wide spectrum of interactions including reduced effects of anticoagulants, oral contraceptives and theophylline (Mason 2010). Additionally, ginseng can interact with the anticlotting drug warfarin; feverfew, ginger and gingko can also interact with aspirin; garlic can interfere with anticlotting medications and the immunosuppressant drug cyclosporine, which prevents transplant rejection (Silver 2001). Black cohosh and glucosamine can pose serious risks when combined with prescription medications like the cancer drug tamoxifen and clotting agents, respectively.

12.6.8 Myotonolytics

Myotonolytics (e.g., tizanidine and baclofen) are often administered as antispastic medication in subjects with a spinal cord injury (Kheder and Nair 2012). Side effects of the medications include nausea and sleepiness. As these substances act centrally, subjects should refrain from alcohol consumption to avoid the intensification of side effects. Further, athletes should drive with caution when being treated with myotonolytics.

12.6.9 Nonsteroidal Anti-Inflammatory Drugs

Nonsteroidal anti-inflammatory drugs (NSAIDs) are widely used to treat mild to moderate pain (such as muscle pain from intense physical activity), inflammation and fever. NSAIDs (e.g., ibuprofen, diclofenac, ketoprofen, naproxen) may induce stomach irritation; thus, it is suggested to ingest the drugs together with food or milk.

Consumption with alcohol potentially increases the risk of liver damage or stomach bleeding (Bushra et al. 2011). The frequent use of NSAIDs may provide short-term benefit to athletes, but they are not benign agents, and like many compounds, they have the potential to nonspecifically influence multiple systems, resulting in harmful side effects (Alexopoulou et al. 2008). The use of NSAIDs as a prophylactic agent can predispose the athletes to these adverse drug reactions, with 1 in 5 athletes reporting some NSAID-related side effects (Suzic Lazic et al. 2011).

12.6.10 Sildenafil

Sildenafil, a selective phosphodiesterase inhibitor, is the standard treatment for men with erectile dysfunction, including athletes with spinal cord injuries. Sildenafil interacts with grapefruit juice as well as with nitrate, which can be found in beetroot or spinach juice (Ishikura et al. 2000; Jetter et al. 2002; Kloner et al. 2003).

12.6.11 Statins (HMG-CoA Reductase Inhibitors)

Statins are widely used to lower blood cholesterol levels. Statins are metabolised by cytochrome P450, one of the most important enzyme systems in drug metabolism. Grapefruit juice interacts with cytochrome P450, so serum concentrations of some statins (e.g., atorvastatin, lovastatin, simvastatin) are increased, whereas others (e.g., pravastatin) are not influenced after grapefruit juice consumption (Kantola et al. 1998; Lilja et al. 1998, 1999).

12.6.12 Iron and Drug Interactions

Iron deficiency is the most prevalent nutritional disorder in the world and is particularly pertinent in athletes (Deakin and Peeling 2015). Among athletes, symptoms of iron deficiency include decreased endurance ability, chronic fatigue and recurring illnesses such as minor infections. Nutrient-drug interaction is one of several known causes of iron deficiency anaemia. Phytates from high-fibre foods inhibit iron absorption, while vitamin C–rich foods enhance iron absorption in the gastrointestinal tract. Medications such as antacids and cholesterol-lowering medications may reduce iron absorption (Medline Plus). Taking iron supplements may help to improve oxygen status and athletic performance; however, iron intake may interact with other drugs, forming iron-drug complexes which affect the bioavailability of the drug. Iron supplements are known to interact with NSAIDs and reduce the effectiveness of levothyroxine and levodopa. When used together with iron supplements, the body may not properly absorb ACE inhibitors, bisphosphonates or tetracyclines (Medline Plus).

12.6.13 Nutrient-Drug Interactions Among Athletes with Impairment and Concomitant Hypertension

High blood pressure, which has long been recognised as an important risk factor for cardiovascular disease and mortality, ranks among the top 10 causes of death globally (Lozano et al. 2012). Drug-drug interactions are common occurrences in the hypertensive population. However nutrient-drug interactions are less appreciated (Sica 2006). The interaction between grapefruit juice and the calcium channel blockers used in hypertension management has been known since 1989. The basis for this interaction appears to relate to both flavanoid and nonflavanoid components of grapefruit juice interfering with enterocyte CYP3A4 activity, leading to increased bioavailability and decreased clearance of the drug from the consumer's system. Felodipine and most other calcium channel blockers are susceptible to this interaction (Sica 2006). Hypertensive athletes who are managed on calcium channel blockers must be made aware of this likely interaction as they pursue controlled blood pressure and aim for adequate nutrient intake.

12.7 CONCLUSION

For all athletes, nutrition is not only a key determinant of overall health, but also an important factor for maximising athletic performance. For the Paralympic athlete, there may be unique nutritional considerations based on impairment. This chapter summarised a number of nutrition-based considerations for athletes with spinal cord injury and cerebral palsy, vision and auditory impairment, amputation and traumatic brain injury. Secondary complications and related health vulnerabilities for each condition were also reviewed. Important drug-nutrient interactions were described, as nutritional supplementation and diet can affect the action of drugs athletes may be taking to manage health conditions – and vice versa. By incorporating nutrition into the management of Para athletes' health, illness and injury, clinicians can optimise clinical health and help enhance sports performance.

REFERENCES

Alexander, J.W. and Supp, D.M. 2014. Role of arginine and omega-3 fatty acids in wound healing and infection. *Advances in Wound Care (New Rochelle)* 3:682–690.

Alexopoulou, A., Dourakis, S.P., Mantzoukis, D. et al. 2008. Adverse drug reactions as a cause of hospital admissions: A 6-month experience in a single center in Greece. *European Journal of Internal Medicine* 19:505–510.

Alviar, M.J., Hale, T. and Dungca, M. 2016. Pharmacologic interventions for treating phantom limb pain. *Cochrane Database of Systematic Reviews* 10:Cd006380.

Atif, F., Sayeed, I., Ishrat, T. and Stein, D.G. 2009. Progesterone with vitamin D affords better neuroprotection against excitotoxicity in cultured cortical neurons than progesterone alone. *Molecular Medicine* 15:328–336.

Barr, R.D. and Wunder, J.S. 2009. Bone and soft tissue sarcomas are often curable-but at what cost?: A call to arms (and legs). *Cancer* 115:4046–4054.

Bazinet R.P. and Laye, S. 2014. Polyunsaturated fatty acids and their metabolites in brain function and disease. *Nature Reviews Neuroscience* 15:771–785.

Beerepoot, M. and Geerlings, S. 2016. Non-antibiotic prophylaxis for urinary tract infections. *Pathogens* 5:36.

Berthold, J., Dicianno, B.E. and Cooper, R.A. 2013. Pressure mapping to assess seated pressure distributions and the potential risk for skin ulceration in a population of sledge hockey players and control subjects. *Disability and Rehabilitation: Assistive Technology* 8:387–391.

Bhambhani, Y., Mactavish, J., Warren, S. et al. 2010. Boosting in athletes with high-level spinal cord injury: Knowledge, incidence and attitudes of athletes in Paralympic sport. *Disability and Rehabilitation* 32:2172–2190.

Bilgi, N., Bell, K., Ananthakrishnan, A.N. and Atallah, E. 2010. Imatinib and Panax ginseng: A potential interaction resulting in liver toxicity. *Annals of Pharmacotherapy* 44:926–928.
Boeing, H., Bechthold, A., Bub, A. et al. 2012. Critical review: Vegetables and fruit in the prevention of chronic diseases. *European Journal of Nutrition* 51:637–663.
Bonjour, J.P. 2011. Calcium and phosphate: A duet of ions playing for bone health. *Journal of the American College of Nutrition* 30:438s–448s.
Boullata, J.I. and Hudson, L.M. 2012. Drug-nutrient interactions: A broad view with implications for practice. *Journal of the Academy of Nutrition and Dietetics* 112:506–517.
Bragaru, M., Dekker, R. and Geertzen, J.H. 2012. Sport prostheses and prosthetic adaptations for the upper and lower limb amputees: An overview of peer reviewed literature. *Prosthetics and Orthotics International* 36:290–296.
Bushra, R., Aslam, N. and Khan, A.Y. 2011. Food-drug interactions. *Oman Medical Journal* 26:77–83.
Cervenka, M.C., Henry-Barron, B.J. and Kossoff, E.H. 2017. Is there a role for diet monotherapy in adult epilepsy? *Epilepsy and Behaviour Case Reports* 7:6–9.
Chavez, M.L., Jordan, M.A. and Chavez, P.I. 2006. Evidence-based drug-herbal interactions. *Life Sciences* 78:2146–2157.
Christison, K., Walter, M., Wyndaele, J.J.M. et al. 2018. Intermittent catheterization: The devil is in the details. *Journal of Neurotrauma*. doi: 10.1089/neu.2017.5413 (Epub ahead of print).
Cirnigliaro, C.M., Myslinski, M.J., La Fountaine, M.F., Kirshblum, S.C., Forrest, G.F. and Bauman, W.A. 2017. Bone loss at the distal femur and proximal tibia in persons with spinal cord injury: Imaging approaches, risk of fracture, and potential treatment options. *Osteoporosis International* 28:747–765.
Cole, J.T., Mitala, C.M., Kundu, S. et al. 2010. Dietary branched chain amino acids ameliorate injury-induced cognitive impairment. *Proceedings of the National Academy of Sciences of the United States of America* 107:366–371.
Compton, S., Trease, L., Cunningham, C. and Hughes, D. 2015. Australian Institute of Sport and the Australian Paralympic Committee position statement: Urinary tract infection in spinal cord injured athletes. *British Journal of Sports Medicine* 49:1236–1240.
Consortium for Spinal Cord Medicine. 2006. Bladder management for adults with spinal cord injury: A clinical practice guideline for health-care providers. *Journal of Spinal Cord Medicine* 29:527–573.
Cowan, H. 2015. Autonomic dysreflexia in spinal cord injury. *Nursing Times* 111:22–24.
Cruse, J.M., Lewis, R.E., Roe, D.L. et al. 2000. Facilitation of immune function, healing of pressure ulcers, and nutritional status in spinal cord injury patients. *Experimental and Molecular Pathology* 68:38–54.
Cruz, C.D. and Cruz, F. 2011. Spinal cord injury and bladder dysfunction: New ideas about an old problem. *Scientific World Journal* 11:214–234.
Curtis, L. 2016. Nutritional research may be useful in treating tendon injuries. *Nutrition* 32:617–619.
Deakin, V. and Peeling, P. 2015. Prevention, detection and treatment of iron depletion. In: *Clinical Sports Nutrition* (5th edn), eds. Burke, L. and Deakin, V. pp. 266–309. Sydney: McGraw-Hill.
Desai, A., Kevala, K. and Kim, H.Y. 2014. Depletion of brain docosahexaenoic acid impairs recovery from traumatic brain injury. *PLOS ONE* 9:e86472. doi: 10.1371/journal.pone.0086472.
Domazetovic, V., Marcucci, G., Iantomasi, T., Brandi, M.L. and Vincenzini, M.T. 2017. Oxidative stress in bone remodeling: Role of antioxidants. *Clinical Cases in Mineral and Bone Metabolism* 14:209–216.
Dorner, B., Posthauer, M.E. and Thomas, D. 2009. The role of nutrition in pressure ulcer prevention and treatment: National Pressure Ulcer Advisory Panel white paper. *Advances in Skin and Wound Care* 22:212–221.

Eser, P., Schiessl, H. and Willnecker, J. 2004. Bone loss and steady state after spinal cord injury: A cross-sectional study using pQCT. *Journal of Musculoskeletal and Neuronal Interactions* 4:197–198.

Everaert, K., Lumen, N., Kerckhaert, W., Willaert, P. and van Driel, M. 2009. Urinary tract infections in spinal cord injury: Prevention and treatment guidelines. *Acta Clinica Belgica* 64:335–340.

Fagher, K. and Lexell, J. 2014. Sports-related injuries in athletes with disabilities. *Scandinavian Journal of Medicine and Science in Sports* 24:e320–331.

Fernandez, M.A., Panahi, S., Daniel, N., Tremblay, A. and Marette, A. 2017. Yogurt and cardiometabolic diseases: A critical review of potential mechanisms. *Advances in Nutrition* 8:812–829.

Frotzler, A., Coupaud, S., Perret, C., Kakebeeke, T.H., Hunt, K.J. and Eser, P. 2009. Effect of detraining on bone and muscle tissue in subjects with chronic spinal cord injury after a period of electrically-stimulated cycling: A small cohort study. *Journal of Rehabilitation Medicine* 41:282–285.

Furedi, P., Papai, K., Budai, M., Ludanyi, K., Antal, I. and Klebovich, I. 2009. *In vivo* effect of food on absorption of fluoroquinolones. *Acta Pharmaceutica Hungaria* 79:81–87.

Giangregorio, L. and McCartney, N. 2006. Bone loss and muscle atrophy in spinal cord injury: Epidemiology, fracture prediction, and rehabilitation strategies. *Journal of Spinal Cord Medicine* 29:489–500.

Glaser, J.D., Bensley, R.P., Hurks, R. et al. 2013. Fate of the contralateral limb after lower extremity amputation. *Journal of Vascular Surgery* 58:1571–1577.

Glickman, S. and Kamm, M.A. 1996. Bowel dysfunction in spinal-cord-injury patients. *Lancet* 347:1651–1653.

Goosey-Tolfrey, V.L. and Crosland, J. 2010. Nutritional practices of competitive British wheelchair games players. *Adapted Physical Activity Quarterly* 27:47–59.

Groah, S.L., Schladen, M., Pineda, C.G. and Hsieh, C.H. 2015. Prevention of pressure ulcers among people with spinal cord injury: A systematic review. *PM & R: The Journal of Injury, Function and Rehabilitation* 7:613–636.

Grobler, L. and Derman, W. 2018. Sport-specific limb prostheses in Para sport. *Physical Medicine and Rehabilitation Clinics of North America* 29:371–385.

Grobler, L., Derman, W., Blauwet, C., Chetty, S., Webborn, N. and Pluim, B. 2018. Pain management in athletes with impairment: A narrative review of management strategies. *Clinical Journal of Sports Medicine* 28:457–472.

Haakonssen, E.C., Ross, M.L., Knight, E.J. et al. 2015. The effects of a calcium-rich pre-exercise meal on biomarkers of calcium homeostasis in competitive female cyclists: A randomised crossover trial. *PLOS ONE* 10:e0123302.

Hagberg, K. and Branemark, R. 2001. Consequences of non-vascular trans-femoral amputation: A survey of quality of life, prosthetic use and problems. *Prosthetics and Orthotics International* 25:186–194.

Hainline, B., Derman, W., Vernec, A. et al. 2017. International Olympic Committee consensus statement on pain management in elite athletes. *British Journal of Sports Medicine* 51:1245–1258.

Hansen, R.B., Biering-Sorensen, F. and Kristensen, J.K. 2010. Urinary incontinence in spinal cord injured individuals 10–45 years after injury. *Spinal Cord* 48:27–33.

Hasadsri, L., Wang, B.H., Lee, J.V. et al. 2013. Omega-3 fatty acids as a putative treatment for traumatic brain injury. *Journal of Neurotrauma* 30:897–906.

de Hon, O. and B. Coumans. 2007. The continuing story of nutritional supplements and doping infractions. *British Journal of Sports Medicine* 41:800–805.

Institute of Medicine, Food and Nutrition Board. 2005. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients).* Washington, DC: Institute of Medicine, Food and Nutrition Board.

Institute of Medicine, Food and Nutrition Board. 2018. National Academy of Sciences (NAS): Dietary reference intakes tables and applications. National Academy of Sciences Last Modified 16 January 2018, Accessed June 3 2018.

Ishikura, F., Beppu, S., Hamada, T., Khandheria, B.K., Seward, J.B. and Nehra, A. 2000. Effects of sildenafil citrate (Viagra) combined with nitrate on the heart. *Circulation* 102:2516–2521.

Iwashita, Y., Ohya, M., Yashiro, M. et al. 2018. Dietary changes involving *Bifidobacterium longum* and other nutrients delays chronic kidney disease progression. *American Journal of Nephrology* 47:325–332.

Jahromi, M.S., Mure, A. and Gomez, C.S. 2014. UTIs in patients with neurogenic bladder. *Current Urology Reports* 15:433.

Jetter, A., Kinzig-Schippers, M., Walchner-Bonjean, M. et al. 2002. Effects of grapefruit juice on the pharmacokinetics of sildenafil. *Clinical Pharmacology and Therapeutics* 71:21–29.

Kantola, T., Kivisto, K.T. and Neuvonen, P.J. 1998. Grapefruit juice greatly increases serum concentrations of lovastatin and lovastatin acid. *Clinical Pharmacology and Therapeutics* 63:397–402.

KDIGO (Kidney Disease: Improving Global Outcomes) CKD Work. 2013. KDIGO 2012 clinical practice guideline for the evaluation and management of chronic kidney disease. *Kidney International Supplements* 3:1–150.

Kern, H., Hofer, C., Loefler, S. et al. 2017. Atrophy, ultra-structural disorders, severe atrophy and degeneration of denervated human muscle in SCI and aging. Implications for their recovery by functional electrical stimulation, updated 2017. *Neurological Research* 39:660–666.

Kheder, A. and Nair, K.P. 2012. Spasticity: Pathophysiology, evaluation and management. *Practical Neurology* 12:289–298.

Klenck, C. and Gebke, K. 2007. Practical management: Common medical problems in disabled athletes. *Clinical Journal of Sport Medicine* 17:55–60.

Kloner, R.A., Hutter, A.M., Emmick, J.T., Mitchell, M.I., Denne, J. and Jackson, G. 2003. Time course of the interaction between tadalafil and nitrates. *Journal of the American College of Cardiology* 42:1855–1860.

Krassioukov, A. 2012. Autonomic dysreflexia: current evidence related to unstable arterial blood pressure control among athletes with spinal cord injury. *Clinical Journal of Sport Medicine* 22:39–45.

Laird, M.D., Sukumari-Ramesh, S., Swift, A.E., Meiler, S.E., Vender, J.R. and Dhandapani, K.M. 2010. Curcumin attenuates cerebral edema following traumatic brain injury in mice: A possible role for aquaporin-4? *Journal of Neurochemistry* 113:637–648.

Laye, S., Nadjar, A., Joffre, C. and Bazinet, R.P. 2018. Anti-inflammatory effects of omega-3 fatty acids in the brain: Physiological mechanisms and relevance to pharmacology. *Pharmacological Reviews* 70:12–38.

Lehto, P., Kivisto, K.T. and Neuvonen, P.J. 1994. The effect of ferrous sulphate on the absorption of norfloxacin, ciprofloxacin and ofloxacin. *British Journal of Clinical Pharmacology* 37:82–85.

Lenoir-Wijnkoop, I., Jones, P.J., Uauy, R., Segal, L. and Milner, J. 2013. Nutrition economics–food as an ally of public health. *British Journal of Nutrition* 109:777–784.

Lewis, M., Ghassemi, P. and Hibbeln, J. 2013. Therapeutic use of omega-3 fatty acids in severe head trauma. *The American Journal of Emergency Medicine* 31:273 e5–8.

Lilja, J.J., Kivisto, K.T. and Neuvonen, P.J. 1998. Grapefruit juice-simvastatin interaction: Effect on serum concentrations of simvastatin, simvastatin acid, and HMG-CoA reductase inhibitors. *Clinical Pharmacology and Therapeutics* 64:477–483.

Lilja, J.J., Kivisto, K.T. and Neuvonen, P.J. 1999. Grapefruit juice increases serum concentrations of atorvastatin and has no effect on pravastatin. *Clinical Pharmacology and Therapeutics* 66:118–127.

Lotan, Y., Daudon, M., Bruyere, F. et al. 2013. Impact of fluid intake in the prevention of urinary system diseases: A brief review. *Current Opinion in Nephrology and Hypertension* 22:S1–10.

Lozano, R., Naghavi, M., Foreman, K. et al. 2012. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: A systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 380:2095–2128.

Lynch, A.C., Antony, A., Dobbs, B.R. and Frizelle, F.A. 2001. Bowel dysfunction following spinal cord injury. *Spinal Cord* 39:193–203.

Madhuvrata, P., Cody, J.D., Ellis, G., Herbison, G.P. and Hay-Smith, E.J. 2012. Which anticholinergic drug for overactive bladder symptoms in adults. *Cochrane Database of Systematic Reviews* 1:Cd005429. doi: 10.1002/14651858.

Magno e Silva, M.P., Morato, M.P., Bilzon, J.L. and Duarte, E. 2013a. Sports injuries in Brazilian blind footballers. *International Journal of Sports Medicie* 34:239–243.

Magno e Silva, M.P., Winckler, C., Silva, E., Costa, A.A., Bilzon, J. and Duarte, E. 2013b. Sports injuries in Paralympic track and field athletes with visual impairment. *Medicine and Science in Sports and Exercicse* 45:908–913.

Malhotra, B., Sachse, R. and Wood, N. 2009. Influence of food on the pharmacokinetic profile of fesoterodine. *International Journal of Clinical Pharmacology and Therapeutics* 47:384–390.

Mason, P. 2010. Important drug-nutrient interactions. *Proceedings of the Nutrition Society* 69:551–557.

Maughan, R.J., Depiesse, F. and Geyer, H. 2007. The use of dietary supplements by athletes. *Journal of Sports Science* 25(Suppl. 1):S103–S113.

Mazzeo, F., Santamaria, S. and Iavarone, A. 2015. "Boosting" in Paralympic athletes with spinal cord injury: Doping without drugs. *Functional Neurology* 30:91–98.

McDowall, J.A. 2007. Supplement use by young athletes. *Journal of Sports Science and Medicine* 6:337–342.

Medline Plus. Trusted Health Information for You. Taking Iron Supplements. U.S. National Library of Medicine, https://medlineplus.gov/ency/article/007478.htm. Last accessed June 2018.

Nakajima, Y., Kaga, K., Takekoshi, H. and Sakuraba, K. 2012. Evaluation of vestibular and dynamic visual acuity in adults with congenital deafness. *Perceptual and Motor Skills* 115:503–511.

Nei, M., Ngo, L., Sirven, J.I. and Sperling, M.R. 2014. Ketogenic diet in adolescents and adults with epilepsy. *Seizure* 23:439–442.

Office of Dietary Supplements (ODS). 2011. Vitamin B12: Fact Sheet for Consumers. National Institutes of Health. https://ods.od.nih.gov/factsheets/VitaminB12-Consumer/ last accessed 11th October 2018.

Owens, D.J., Allison, R. and Close, G.L. 2018. Vitamin D and the athlete: Current perspectives and new challenges. *Sports Medicine* 48(Suppl. 1):3–16.

Pannek, J. and Wollner, J. 2017. Management of urinary tract infections in patients with neurogenic bladder: Challenges and solutions. *Research and Reports in Urology* 9:121–127.

Papai, K., Budai, M., Ludanyi, K., Antal, I. and Klebovich, I. 2010. *In vitro* food-drug interaction study: Which milk component has a decreasing effect on the bioavailability of ciprofloxacin? *Journal of Pharmaceutical and Biomedical Analysis* 52:37–42.

Pasca, L., De Giorgis, V., Macasaet, J.A., Trentani, C., Tagliabue, A. and Veggiotti, P. 2016. The changing face of dietary therapy for epilepsy. *European Journal of Pediatrics* 175:1267–1276.

Peng, C.C., Glassman, P.A., Trilli, L.E., Hayes-Hunter, J. and Good, C.B. 2004. Incidence and severity of potential drug-dietary supplement interactions in primary care patients: An exploratory study of 2 outpatient practices. *Archives of Internal Medicine* 164:630–636.

Petraglia, A.L., Winkler, E.A. and Bailes, J.E. 2011. Stuck at the bench: Potential natural neuroprotective compounds for concussion. *Surgical Neurology International* 2:146.

Polk, R.E., Healy, D.P., Sahai, J., Drwal, L. and Racht, E. 1989. Effect of ferrous sulfate and multivitamins with zinc on absorption of ciprofloxacin in normal volunteers. *Antimicrobial Agents and Chemotherapy* 33:1841–1844.

Poortmans, J.R., Carpentier, A., Pereira-Lancha, L.O. and Lancha, A. Jr. 2012. Protein turnover, amino acid requirements and recommendations for athletes and active populations. *Brazilian Journal of Medical and Biological Research* 45:875–890.

Porras, A.G., Holland, S.D. and Gertz, B.J. 1999. Pharmacokinetics of alendronate. *Clinical Pharmacokinetics* 36:315–328.

Price, M.J. 2006. Thermoregulation during exercise in individuals with spinal cord injuries. *Sports Medicine* 36:863–879.

Pritchett, K., Pritchett, R.C., Stark, L., Broad, E. and LaCroix, M. 2018. Effect of vitamin D supplementation on 25(OH)D status in elite athletes with spinal cord injury. *International Journal of Sport Nutrition and Exercise Metabolism* 14:1–23.

Puhaindran, M.E., Chou, J., Forsberg, J.A. and Athanasian, E.A. 2012. Major upper-limb amputations for malignant tumors. *The Journal of Hand Surgery* 37:1235–1241.

Regan, M.A., Teasell, R.W., Wolfe, D.L., Keast, D., Mortenson, W.B. and Aubut, J.A. 2009. A systematic review of therapeutic interventions for pressure ulcers after spinal cord injury. *Archives of Physical Medicine and Rehabiliation* 90:213–231.

Rondanelli, M., Faliva, M.A., Miccono, A. et al. 2018. Food pyramid for subjects with chronic pain: Foods and dietary constituents as anti-inflammatory and antioxidant agents. *Nutrition Research Reviews* 31:131–151.

Ruscin, J.M., Page, R.L. and Valuck, R.J. 2002. Vitamin B(12) deficiency associated with histamine(2)-receptor antagonists and a proton-pump inhibitor. *Annals of Pharmacotherapy* 36:812–816.

Saghaleini, S.H., Dehghan, K., Shadvar, K., Sanaie, S., Mahmoodpoor, A. and Ostadi, Z. 2018. Pressure ulcer and nutrition. *Indian Journal of Critical Care Medicine* 22:283–289.

Sakai, R., Cohen, D.M., Henry, J.F., Burrin, D.G. and Reeds, P.J. 2004. Leucine-nitrogen metabolism in the brain of conscious rats: Its role as a nitrogen carrier in glutamate synthesis in glial and neuronal metabolic compartments. *Journal of Neurochemistry* 88:612–622.

Sakellaris, G., Kotsiou, M., Tamiolaki, M. et al. 2006. Prevention of complications related to traumatic brain injury in children and adolescents with creatine administration: An open label randomized pilot study. *Journal of Trauma* 61:322–329.

Salas-Salvado, J., Becerra-Tomas, N., Garcia-Gavilan, J.F., Bullo, M. and Barrubes, L. 2018. Mediterranean diet and cardiovascular disease prevention: What do we know? *Progress in Cardiovascular Diseases* 61:62–67.

Santos-Parker, J.R., Strahler, T.R., Bassett, C.J., Bispham, N.Z., Chonchol, M.B. and Seals, D.R. 2017. Curcumin supplementation improves vascular endothelial function in healthy middle-aged and older adults by increasing nitric oxide bioavailability and reducing oxidative stress. *Aging* 9:187–208.

Scaramella, J., Kirihennedige, N. and Broad, E. 2018. Key nutritional strategies to optimize performance in Para athletes. *Physical Medicine and Rehabilitation Clinics of North America* 29:283–298.

Schober, M.E., Requena, D.F., Abdullah, O.M. et al. 2016. Dietary docosahexaenoic acid improves cognitive function, tissue sparing, and magnetic resonance imaging indices of edema and white matter injury in the immature rat after traumatic brain injury. *Journal of Neurotrauma* 33:390–402.

Sears, B. 2015. Anti-inflammatory diets. *Journal of the American College of Nutrition* 34(Suppl. 1):14–21.

Segal, A.D. and Klute, G.K. 2016. Residual limb skin temperature and thermal comfort in people with amputation during activity in a cold environment. *Journal of Rehabilitation Research and Development* 53:619–628.

Sharma, S., Ying, Z. and Gomez-Pinilla, F. 2010. A pyrazole curcumin derivative restores membrane homeostasis disrupted after brain trauma. *Experimental Neurology* 226:191–199.

Shaw, G., Lee-Barthel, A., Ross, M.L., Wang, B. and Baar, K. 2017. Vitamin C-enriched gelatin supplementation before intermittent activity augments collagen synthesis. *American Journal of Clinical Nutrition* 105:136–143.

Shepherd, A.A. 2003. Nutrition for optimum wound healing. *Nursing Standard* 18:55–58.

Shimizu, Y., Mutsuzaki, H., Tachibana, K. et al. 2017. A survey of deep tissue injury in elite female wheelchair basketball players. *Journal of Back and Musculoskeletal Rehabilitation* 30:427–434.

Sica, D.A. 2006. Interaction of grapefruit juice and calcium channel blockers. *American Journal of Hypertension* 19:768–773.

Siddiqui, S., Sifonios, A.N., Le, V., Martinez, M.E., Eloy, J.D. and Kaufman, A.G. 2014. Development of phantom limb pain after femoral nerve block. *Case Reports in Medicine* 2014:238453. doi: 10.1155/2014/238453.

Silver, M.D. 2001. Use of ergogenic aids by athletes. *Journal of the American Academy of Orthopaedic Surgeons* 9:61–70.

Singh, D. and Asad, M. 2010. Effect of soybean administration on the pharmacokinetics of carbamazepine and omeprazole in rats. *Fundamental and Clinical Pharmacology* 24:351–355.

Sonmez, U., Sonmez, A., Erbil, G., Tekmen, I. and Baykara, B. 2007. Neuroprotective effects of resveratrol against traumatic brain injury in immature rats. *Neuroscience Letters* 420:133–137.

Sostek, M.B., Chen, Y. and Andersson, T. 2007. Effect of timing of dosing in relation to food intake on the pharmacokinetics of esomeprazole. *British Journal of Clinical Pharmacology* 64:386–390.

Spinu, A., Onose, G., Daia, C. et al. 2012. Intermittent catheterization in the management of post spinal cord injury (SCI) neurogenic bladder using new hydrophilic, with lubrication in close circuit devices – Our own preliminary results. *Journal of Medicine and Life* 5:21–28.

Stone, A.R. 1987. The sexual needs of the injured spinal cord patient. *Problems in Urology* 3:529–536.

Sun, G.Y., Simonyi, A., Fritsche, K.L. et al. 2017. Docosahexaenoic acid (DHA): An essential nutrient and a nutraceutical for brain health and diseases. *Prostaglandins, Leukotrienes and Essential Fatty Acids*. doi: 10.1016/j.plefa.2017.03.006. [Epub ahead of print]

Suzic Lazic, J., Dikic, N., Radivojevic, N. et al. 2011. Dietary supplements and medications in elite sport-polypharmacy or real need? *Scandinavian Journal of Medicine and Science in Sports* 21:260–267.

Tate, D.G., Forchheimer, M., Rodriguez, G. et al. 2016. Risk factors associated with neurogenic bowel complications and dysfunction in spinal cord injury. *Archives of Physical Medicine and Rehabilitation* 97:1679–1686.

ter Riet, G., Kessels, A.G. and Knipschild, P.G. 1995. Randomized clinical trial of ascorbic acid in the treatment of pressure ulcers. *Journal of Clinical Epidemiology* 48:1453–1460.

Thomas, D.T., Erdman, K.A. and Burke, L.M. 2016. American college of sports medicine joint position statement. Nutrition and athletic performance. *Medicine and Science in Sports and Exercise* 48:543–68.

Tuakli-Wosornu, Y.A., Mashkovskiy, E., Ottesen, T., Gentry, M., Jensen, D. and Webborn, N. 2018. Acute and chronic musculoskeletal injury in Para sport: A critical review. *Physical Medicine and Rehabilitation Clinics or North America* 29:205–243.

Van de Vliet, P. 2012. Paralympic athlete's health. *British Journal of Sports Medicine* 46:458–459.

Verschuren, O., Smorenburg, A.R.P., Luiking, Y., Bell, K., Barber, L. and Peterson, M.D. 2018. Determinants of muscle preservation in individuals with cerebral palsy across the lifespan: a narrative review of the literature. *Journal of Cachexia, Sarcopenia and Muscle* 9:453–464.

Wall, B.T., Morton, J.P. and van Loon, L.J.C. 2015. Strategies to maintain skeletal muscle mass in the injured athlete: Nutritional considerations and exercise mimetics. *European Journal of Sport Science* 15:53–62.

Walter, M. and Krassioukov, A.V. 2018. Autonomic nervous system in Paralympic athletes with spinal cord injury. *Physical Medicine and Rehabilitation Clinics of North America* 29:245–266.

Webborn, N. and Emery, C. 2014. Descriptive epidemiology of Paralympic sports injuries. *PM & R* 6(8 Suppl.):S18–22.

Webborn, N. and Van de Vliet, P. 2012. Paralympic medicine. *Lancet* 380:65–71.

Winterstein, A.P. and Storrs, C.M. 2001. Herbal supplements: Considerations for the athletic trainer. *Journal of Athletic Training* 36:425–432.

Wu, C.L., Kor, C.T., Chiu, P.F. et al. 2017. Long-term renal outcomes in patients with traumatic brain injury: A nationwide population-based cohort study. *PLOS ONE* 12(2):e0171999.

Zehnder, Y., Risi, S., Michel, D. et al. 2004. Prevention of bone loss in paraplegics over 2 years with alendronate. *Journal of Bone and Mineral Research* 19:1067–1074.

Zygun, D.A., Kortbeek, J.B., Fick, G.H. et al. 2005. Non-neurologic organ dysfunction in severe traumatic brain injury. *Critical Care Medicine* 33:654–660.

13 Assessing Body Composition of Athletes

Gary Slater and Victoria Goosey-Tolfrey

CONTENTS

13.1 INTRODUCTION

There may be several reasons for undertaking physique assessment amongst athletes with an impairment, including general health screens, risk of heat stress, appropriate sizing/fitting or design of prostheses and other devices, talent identification initiatives or routine monitoring of adaptations to training and diet. The rationale for assessment and outcome measures of interest will play a key role in ascertaining which physique assessment technique and normative data to use in assisting to interpret the data collected. Consideration must also be given to the individual athlete and their specific impairment. This may have implications in either the practical administration of the assessment technique and/or the unique physical characteristics which violate underlying assumptions associated with a specific physique assessment technique. For example, the spasm often associated with multiple sclerosis (MS), cerebral palsy (CP) and spinal cord injury (SCI) would corrupt dual energy x-ray absorptiometry (DXA) scan integrity but have little impact on data captured using air displacement plethysmography (BOD POD) (Rosendale and Bartok 2012; Tegenkamp et al. 2011). In contrast, it would be logistically easier to position an athlete with quadriplegia on a DXA scanner than a BOD POD where they would be unable to maintain body position. Marked changes in total body water (TBW) content and/or the ratio of intracellular to extracellular water, common amongst individuals with a SCI (Kocina 1997), may preclude body composition assessment using bioelectrical impedance (BIA) analysis (Strauss et al. 2000), but less so for BOD POD (Clasey and Gater 2005). Thus, the choice of technique or equipment is a very important aspect to consider when undertaking physique assessment amongst athletes with an impairment.

A relationship between competitive success and physique traits has been identified amongst able-bodied athletes across a range of sports, including rugby (Olds 2001), aesthetically judged sports (Claessens et al. 1999), swimming (Siders et al. 1993), track and field events (Claessens et al. 1994), skiing (Larsson and Henriksson-Larsen 2008; Stoggl et al. 2010; White and Johnson 1991) and rowing (Shephard 1998). Similar relationships likely exist between physique traits and competitive success amongst athletes with an impairment, especially those in which physique traits are not impacted by the condition, such as athletes with intellectual or vision impairment. Less is known about the unique population of Para athletes in which the condition impacts physique traits, such as those with SCI, CP, short stature and amputees. However, athletes within the same classification can have markedly different physique traits (Dingley et al. 2015). There is at least some evidence confirming physique traits do impact performance in this population (Ide et al. 1994; Dingley et al. 2015; Medeiros et al. 2016). The impact of impairments on presenting physique traits and response to interventions such as diet and exercise are addressed in earlier chapters of this book. What is more pertinent in the current chapter is the impact a presenting condition may have on the techniques (or their associated assumptions) available for physique assessment, classification of physique traits and disease risk cut-offs, or the broader application of physique assessment to specific populations such as the fitting of prostheses for amputees.

13.2 PHYSIQUE ASSESSMENT TECHNIQUES

A wide array of techniques are available for the measurement of body composition, including anthropometric, radiographic (computed tomography [CT], DXA) and other medical imaging techniques (magnetic resonance imaging [MRI], ultrasound), metabolic (creatinine, 3-methylhistidine), nuclear (total body potassium, total body nitrogen) and BIA techniques. When selecting the most appropriate technique, a range of factors should be considered, including:

- Technical issues such as the safety, validity, precision and accuracy of measurement
- Practical issues such as availability, financial implications, portability, invasiveness, time effectiveness and technical expertise necessary to conduct the procedures
- The rationale for assessment and outcome measures of interest
- The ability of body composition assessment methodologies to accommodate the unique physique traits characteristic of some athletes with an impairment
- The athlete's impairment and the impact this may have on the assessment itself or subsequent estimation of body composition, and assumptions associated with this

Table 13.1 provides an overview of the most common techniques potentially available for the assessment of body composition (i.e. fat and fat free mass) and broader physique traits (i.e. body fat, muscle mass, bone mass, limb lengths, breadths, proportionality) among athletes with an impairment. Consideration is also given to

TABLE 13.1
Physique Assessment Techniques Potentially Available for Assessment of Body Composition and Physique Traits of Athletes with an Impairment

Technique	Information Provided	Unsuitable for…
BOD POD	FM, FFM	SCI, amputee
DXA	FM, FFM, BMC	MS, CP with spasm. BMC unable to be assessed where metal is present
BIA	FM, FFM, TBW	Oedema, lower body or unilateral amputee, SCI
Anthropometry	Skinfolds, girths, bone breadths and lengths	If absolute FM and FFM measures are required. Modifications to protocol may be required

Note: Consideration is given to the unique characteristics of these athletes and the impact this has on techniques available for assessment.

Abbreviations: BOD POD, Air displacement plethysmography; DXA, Dual Energy x-ray absorptiometry; BIA, Bioelectrical impedance analysis; FM, Fat mass; FFM, Fat free mass; BMC, Bone mineral density; TBW, Total body water; SCI, Spinal cord injury; MS, Multiple sclerosis

the unique characteristics of these athletes and the impact these can have on viable techniques for assessment.

The following section reviews the most common techniques used to assess the physique traits of athletes with an impairment with a focus on the technical or procedural aspects associated with their use (Figure 13.1).

13.2.1 Air Displacement Plethysmography

Air displacement plethysmography uses basic gas laws to describe the inverse relationship between pressure and volume in two enclosed chambers, consequently allowing for the calculation of body density and body composition. Measurement involves sitting briefly in an enclosed chamber, which accommodates a range of subject types (Dempster and Aitkens 1995), while the volume of air displaced by the body is measured. Thereafter, lung functional residual capacity is measured using pulmonary plethysmography or, if this is not possible, predicted based on age, gender and stature. Body density is then calculated by dividing the measured body mass by corrected body volume, with subsequent calculation of percent body fat using either the Siri (1993) or Brozek (Brozek et al. 1963) equations. As such, the BOD POD is constrained by the same issues as hydrodensitometry when converting a measure of body density into body composition, including an assumed fixed density of fat free mass (FFM), which can clearly vary in those with a SCI given differing proportions of minerals, water and protein, invalidating this assumption (Goosey-Tolfrey et al. 2016). While this can be corrected by directly measuring mineral (DXA) and water (deuterium dilution) content, the process is resource intensive, precluding it from routine athlete monitoring. Consequently, body fat estimates of athletes with muscle atrophy via the BOD POD are typically lower than those reported for DXA (Goosey-Tolfrey et al. 2016). The presence of surgical implants such as orthopaedic pins will

FIGURE 13.1 Weighing athletes with a spinal cord injury without a set of seated scales.

also increase body density, further increasing estimates of FFM while simultaneously reducing estimates of body fat. However, this is unlikely to impact interpretation of body composition changes over time, assuming pins remain between assessments. Standard operating procedures applied to able-bodied athletes remain relevant for Para athletes. Consequently, athletes are advised to wear standardised, metal-free and tight-fitting swimsuits (Fields et al. 2000; King et al. 2006; Vescovi et al. 2002) in conjunction with a silicone swimcap (Peeters and Claessens 2011) and to remove excess facial hair (Higgins et al. 2001). Changes in body temperature and moisture content may also influence BOD POD data (Fields et al. 2004), suggesting that assessments should be undertaken independent of exercise. This is further supported by the fact that acute dehydration also influences BOD POD results, underestimating both body fat percentage and FFM, although the effect is within the range of 1% body fat (Utter et al. 2003).

BOD POD test procedures are much less labour intensive than hydrodensitometry for both subjects and technicians and lower the risk of complications in populations such as those with a SCI, where aspiration and autonomic dysreflexia are possible (Clasey and Gater 2005). The measurement of functional residual capacity using pulmonary plethysmography is both reliable and valid in able-bodied populations (Davis et al. 2007), but this may not be the case for individuals with a SCI (Clasey and Gater 2005), impacting estimates of body composition. Indeed, it may be impossible for individuals with high-level SCI (above T6) to undertake a measure of functional residual capacity due to compromised use of assistive respiratory and abdominal musculature (Clasey and Gater 2005). As such, residual capacity should be measured where possible but never used interchangeably with predicted thoracic gas volume (Minderico et al. 2008). Slight body movements during testing, not dissimilar to those likely from tremor, do not appear to influence BOD POD estimates of body composition (Tegenkamp et al. 2011) (Figures 13.2 and 13.3).

While assumptions associated with the fixed density of the FFM may preclude use of the BOD POD in isolation to accurately quantify absolute body composition amongst athletes with muscle atrophy, this may not preclude its ability to accurately

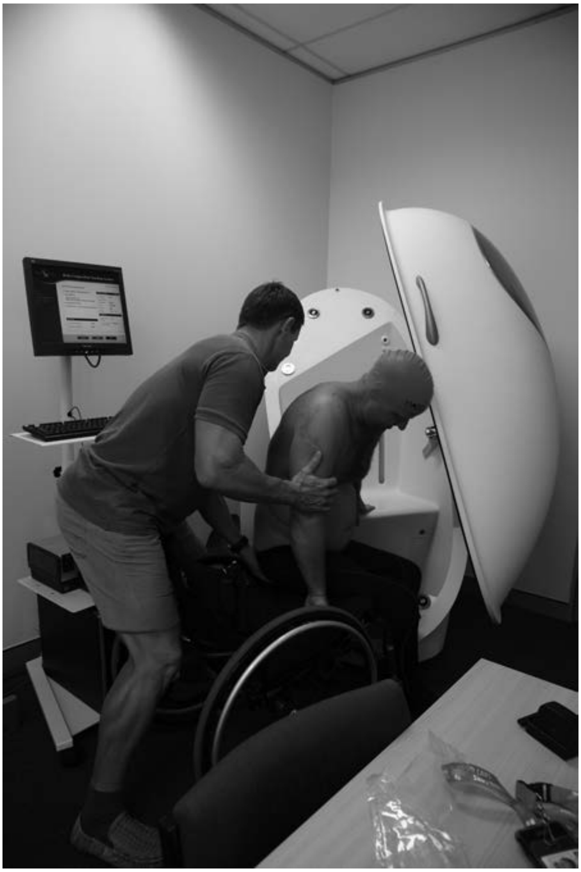


FIGURE 13.2 Assisting a subject into a BOD POD. Note the silicone cap used on the head.

FIGURE 13.3 Undertaking a BOD POD assessment.

track changes in physique traits of these and other Para-sport athletes. Perhaps the greatest limitation to the use of BOD POD to assess body composition amongst athletes with impairments is its limited availability, typically being restricted to tertiary training or research institutes.

13.2.2 Dual Energy X-Ray Absorptiometry

DXA was originally developed for the diagnosis of osteoporosis and remains the reference method for this assessment (Lewiecki 2005). It may also have application as a screening tool in identifying athletes at risk of stress fractures (Kelsey et al. 2007; Prouteau et al. 2004). Furthermore, DXA technology is able to measure soft tissue body composition and has rapidly gained popularity in recent years as one of the most widely used and accepted laboratory-based methods for body composition assessment amongst athletic populations (Meyer et al. 2013). DXA not only provides a measure of fat mass (FM) and FFM, it also provides information on regional body composition, making it unique among physique assessment tools and particularly appealing for athletes with an impairment such as those with SCI, where regional changes in fat, bone and muscle mass can be marked but somewhat masked at a whole-body level. Furthermore, whole body scans are rapid, noninvasive and associated with very low radiation doses, making the technology safe for longitudinal monitoring of body composition, and considered valid amongst those with a SCI (Jones et al. 1998). Because of its application in the assessment of bone mineral density (Miyahara et al. 2008), DXA technology is also becoming increasingly available through commercial imaging centres.

DXA technology is based on the differential attenuation of transmitted photons at two energy levels by bone, fat and lean tissue (Mazess et al. 1990). The differential attenuations are then expressed as a ratio, the outcome of which is specific to different molecular components, including fatty acids, protein and bone. In theory, assessment of all three components would require measurement at three different photon energies. The DXA dual energy system can thus only be used to estimate the fractional masses of two components in any one pixel. That is, in bone-containing pixels, bone mineral and soft tissue can be measured, while in non–bone containing pixels, fat and bone-mineral-free lean can be measured (Pietrobelli et al. 1996). The proportion of fat and bone-mineral-free lean in bone-containing pixels is assumed to be the same as the adjacent non–bone containing pixels (Pietrobelli et al. 1996), with the software subsequently converting individual pixel data into whole-body output. This assumed ratio of fat to bone-mineral-free lean in soft tissue pixels is applied to upwards of one-third of pixels in a whole-body scan of an able-bodied athlete and is particularly evident in regions of low bone-free pixels such as the thorax, arm or head, resulting in less reliable identification of composition changes in these regions (Lands et al. 1996; Roubenoff et al. 1993). This will likely be an issue for accurately quantifying absolute body composition in several Para athletes, including those with a SCI, short stature, CP or bilateral above-knee amputations, because of the greater number of regions of low bone-free pixels. However it does not appear to impact measurement precision, at least when assessed within day (Keil et al. 2016).

In an effort to enhance precision of DXA measurement, special consideration should be given to subject positioning (Lambrinoudaki et al. 1998; Lohman et al. 2009), which may be particularly challenging for those with lordosis or congenital conditions affecting the spine, spasticity or other conditions associated with uncontrolled movement. Clothing should be kept to a minimum (Koo et al. 2004), with all metal objects removed. Surgically placed metal rods, common amongst trauma-induced SCI athletes, significantly influence estimates of bone mineral density (BMD), FM and FFM (Madsen et al. 1999), and, as such, should be accounted for postanalysis when accurate quantification of BMD and body composition is required. Deactivating the manufacturer's default automated regions of interest may be necessary for some Para-sport athletes, including those with short stature or SCI with associated metal rods.

While small amounts of food and fluid do not appear to influence results (Vilaca et al. 2009), larger volumes influence measurement of lean body mass (Kerr et al.

2017); thus, measurements should be undertaken in a fasted state wherever possible, preferably soon after waking in a euhydrated state (Hind et al. 2018). The altered water distribution and associated oedema of the lower limbs common amongst athletes with a SCI (Buchholz et al. 2003) can result in a significant overestimation of FFM (Figures 13.4 and 13.5).

The use of foam pads and straps that are not identified by the DXA scanner are recommended to enhance the reliability of DXA measurements (Nana et al. 2012), and may be particularly valuable for athletes with an impairment who experience tremor, spasticity or other movement during measurement, which, if left uncontrolled, would corrupt results. Given these limitations, DXA technology can be and has been used to assess the body composition of individuals across a range of Para-sport classifications, including SCI (Goosey-Tolfrey et al. 2016; Keil et al. 2016; Mojtahedi et al. 2009; Sutton et al. 2009; Willems et al. 2015).

FIGURE 13.4 Standardising the positioning of an athlete for a DXA scan. Note the use of foam pads to enable consistent positioning and separation of limbs. The foam is not detectable by the DXA scanner.

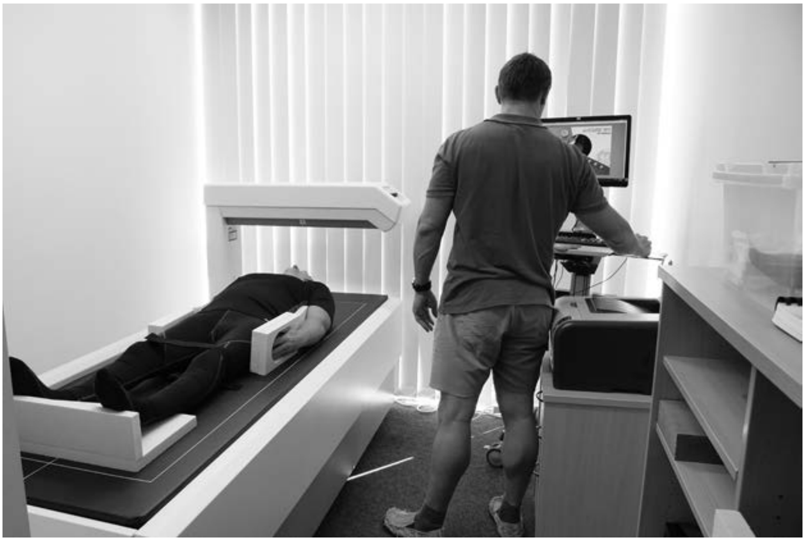


FIGURE 13.5 Undertaking a DXA scan.

13.2.3 Bioelectrical Impedance Analysis

BIA has become increasingly popular as a tool for assessing the body composition of athletes given its relative ease of use, portability and cost effectiveness. It is a safe and noninvasive method to assess body composition that is based on the differing electrical conductivity of FM and FFM (Kyle et al. 2004a; National Institutes of Health 1996). FFM contains water and electrolytes and is a good electrical conductor, while anhydrous FM is not. The method involves measuring the resistance (R) to flow of a low-level current (Kyle et al. 2004a). Resistance is proportional to the length (L) of the conductor (in this case the human body) and inversely proportional to its cross-sectional area (A). A relationship then exists between the impedance quotient (i.e. L^2/R) and the volume of water (total body water) which contains electrolytes that conduct the electrical current. In practise, height in centimetres is substituted for length. Therefore, a relationship exists between FFM (approximately 73% water) and height $(cm)^2/R$. FM is obtained from FFM by subtracting the value for FFM from total body mass (Kyle et al. 2004a).

Due to the relevance of body water to conductivity of electrical current, there is substantial evidence that BIA is not valid for assessment of individuals with abnormal hydration such as visible oedema, ascites, kidney, liver and cardiac disease and pregnancy (Kyle et al. 2004b). Oedema in particular may be common amongst some athletes with an impairment, including those with a SCI (Kocina 1997), with this effect exacerbated by changes in hydration status as a consequence of exercise-induced hypohydration and acute food/fluid intake. Exercise-induced hypohydration to a level of 3% body mass has been shown to decrease the estimate of FM via BIA by 1.7%. Conversely, acute rehydration increased estimates of FM by 3.2%, with a further increase in the estimate of FM as a state of hyperhydration was achieved (Saunders et al. 1998). Even the ingestion of relatively small volumes of fluid (591 mL) has been shown to increase estimates of FM (Dixon et al. 2009). Consequently, athletes should remain fasted for at least 8 h prior to assessment (Kyle et al. 2004a). Given this, it would be prudent to undertake assessments in the morning prior to breakfast wherever possible, with athletes encouraged to present in a well-hydrated state; assessment of which could be done via the collection of a first-morning urine sample.

Other factors reported to influence BIA results include posture and positioning of the limbs (Allison et al. 1995), prior exercise, skin temperature (Kushner et al. 1996) and electrode placement (Dunbar et al. 1994). A detailed description of factors to consider when undertaking assessments using BIA is given elsewhere (Kyle et al. 2004b). The selection of appropriate prediction equations for the conversion of raw impedance results into FFM is an important consideration, with equations derived from untrained individuals likely to be inappropriate for an athletic population (Pichard et al. 1997). Kyle and associates (2004a) provide an excellent summary of prediction equations derived from healthy subjects, and published since 1990, for adults for FFM, body fat and TBW. To date, no equations have been established from populations with character traits similar to those likely amongst athletes with an impairment, making the conversion of raw impedance data into estimates of body composition lacking validation. Foot-to-foot BIA analysers are the most readily available for public purchase (Jaffrin 2009). These inexpensive body-fat "scales" are popular amongst the general public, being promoted as a simple, portable method of measuring body fatness. However, there are a number of limitations with foot-to-foot devices, as current is only circulated through the legs and lower part of the trunk with results extrapolated to the whole body (Jaffrin 2009). This equipment is also limited to those individuals who can freely stand on both legs, limiting its application amongst several classifications of athletes with an impairment. Furthermore, raw impedance data is rarely reported, making selection of population-specific equations impossible. Taken collectively, the nuances associated with many impairment types preclude the use of BIA amongst the majority of Para athletes (Goosey-Tolfrey et al. 2016).

13.2.4 Surface Anthropometry

For reasons of timeliness, practicality and cost effectiveness, the routine monitoring of body composition among athletic populations is most often undertaken using anthropometric characteristics such as body mass plus subcutaneous skinfold thicknesses and girths at specific anatomical landmarks (Meyer et al. 2013). Unlike other techniques requiring expensive laboratory based equipment, surface anthropometry only requires relatively inexpensive equipment that is easily portable. However, highly skilled technicians are required if reliable data are to be collected. Technicians need to be meticulous in terms of both accurate site location and measurement technique. Measurements just 1–2 cm away from a defined site can produce significant differences in results (Hume and Marfell-Jones 2008; Ruiz et al. 1971). Furthermore, if repeat measurements are to be taken over time, it is important that the same technician collect the data (Hume and Marfell-Jones 2008).

The measurement of "skinfolds" or a double layer of skin and subcutaneous tissue as an index of whole body fat would appear to be reasonable. However, what is really being measured is the thickness of a double fold of skin and compressed subcutaneous adipose tissue (Martin et al. 1985). To infer from this the mass or percentage of total body fat requires a number of assumptions to be made, including:

- Constant compressibility of skinfolds across sites on the body
- The skin thickness at any one site is negligible or a constant fraction of a skinfold
- Fixed adipose tissue patterning across the body
- A constant fat fraction in adipose tissue
- Fixed proportion of internal to external fat

When assessed via cadaver analysis, few of these assumptions hold true (Clarys et al. 2005). For example, skinfold compressibility is not constant between sites, and as a consequence, similar thicknesses of adipose tissue may yield different calliper values due to different degrees of tissue compressibility (Marfell-Jones et al. 2003). Furthermore, the patterning of adipose tissue varies markedly between individuals (Mueller and Stallones 1981), and as such, multiple skinfold sites should be used, including both upper- and lower-body landmarks (Eston et al. 2005). The impact of SCI on body fat distribution above and below the lesion remains to be fully elucidated, making it difficult to ascertain if assessments should include sites both above and below the lesion. However, the ratio of visceral to subcutaneous adipose tissue is proportionally higher amongst those with a SCI (Edwards et al. 2008), at least in an untrained population. As such, practitioners are encouraged to focus on upper-body skinfolds and body mass and complement this with a waist girth when monitoring SCI athletes longitudinally. The use of several skinfolds will help enhance sensitivity of assessments to track change while also accounting for individual variance in fat patterning.

Estimates of body density, FM and/or FFM can be derived from raw skinfold data using one of many available regression equations. Altogether, more than 100 equations to predict body fat from skinfolds have been produced (Clarys et al. 1987; Lohman 1981; Martin et al. 1985). However, these equations are typically based on a single measurement, between-subject, cross-sectional comparison of anthropometric parameters and laboratory-based techniques such as hydrodensitometry (Cisar et al. 1989), increasing the assumptions made. Furthermore, these predictive equations have been proven to lack validity in both male (Bulbulian et al. 1987) and female (Sutton et al. 2009) athletes with a SCI, with the exception of a small number of equations, which incorporate girth measurements into estimates of body composition (Goosey-Tolfrey et al. 2016; Withers et al. 1987). However, the ability of these equations to track changes in body composition in response to training and/or dietary interventions has not been widely assessed (Cisar et al. 1989; Wilmore et al. 1970). Preliminary data suggests popular skinfold based models, including those derived from athletes, lack the sensitivity to track small but potentially important changes in body composition (Silva et al. 2009; van Marken Lichtenbelt et al. 2004). Amongst wheelchair sport athletes, regression equations underestimate body fat relative to DXA, an effect which is exacerbated amongst those who are wheelchair dependent (Willems et al. 2015). As such, it seems unreasonable to introduce further error by transforming raw skinfold data into estimates of fat mass or percentage body fat. Thus, despite the advancement in physique assessment techniques, and the notable desire of many athletes wishing to know their "body fat percentage," practitioners are better off to continue using raw anthropometric data rather than attempting to make estimates of whole-body composition from available equations.

While sums of skinfolds are highly correlated with body fat percentage, FFM correlates poorly with skinfolds (Roche 1996). It has been proposed that combining skinfolds with certain body circumferences leads to a better estimate of FFM (Forbes 1999). In theory, skinfold-corrected circumferences offer a more direct assessment of muscle mass, assuming that the skinfold thickness accurately partitions fat and lean components at a specific site (Reid et al. 1992). However, skinfold-corrected girth estimates have been shown to be less accurate in monitoring changes in muscle mass than predictions using skinfolds alone (Cisar et al. 1989; Stewart and Hannan 2000). This imprecision may be explained, at least in part, by the fact that muscle hypertrophy does not occur uniformly throughout each body region (Abe et al. 2003), yet the anthropometric fractionation estimate of muscle mass places equal weighting on each of five girth measurements (Drinkwater and Ross 1980). Consequently, anthropometric fractionation may not be appropriate when attempting to quantify skeletal muscle mass in athletes with significant muscle hypertrophy (Keogh et al. 2007) (Table 13.2).

While surface anthropometry does not offer a direct measure of total FM or FFM, its robustness in the field, convenience and low cost ensure it remains a popular method of body composition monitoring amongst athletes. Newer technologies like DXA offer an opportunity to better interpret surface anthropometry data. Preferably, this should be developed around interpretation of changes in body composition over time rather than a one-off assessment. Such longitudinal investigations also create opportunities to help better understand the association between physique traits and competitive success.

TABLE 13.2
Interpretation of Changes in Body Composition Based on Skinfold and Body Mass Data

Anthropometric Trait		Interpretation – Body Composition	
Body Mass	**Skinfolds**	**Muscle Mass**	**Body Fat**
Increase	Stable	Gain	No change
Decrease	Stable	Loss	No change
Stable	Increase	Loss	Gain
Stable	Decrease	Gain	Loss
Increase	Increase	Potential Gain	Gain
Increase	Decrease	Gain	Loss
Decrease	Increase	Loss	Gain
Decrease	Decrease	Potential Loss	Loss

FIGURE 13.6 Undertaking skinfold measurements. Note the landmarking of sites per ISAK requirements.

Precise assessment of anthropometric traits, in particular skinfold thickness, can be difficult and therefore extreme care in site location and measurement is required if meaningful results are to be obtained. Prior to assessment, the tester should develop the appropriate technique, reducing the level of error in repeated measurements, and thus enhancing the ability to detect small but potentially important changes. The standard assessment protocol of the International Society for the Advancement of Kinanthropometry (ISAK) (Stewart et al. 2011) is recommended. Professionals wishing to monitor the physique traits of athletes using surface anthropometry are strongly encouraged to undertake professional training through accredited courses (Figure 13.6).

13.3 FACTORS INFLUENCING RELIABILITY OF METHODS

A wide range of tools are available to assess the physique traits of athletes. Aside from talent identification initiatives and the identification of a preferred physique for a given sport and player position, the primary focus is given to the longitudinal monitoring of physique traits. As such, techniques that are cost and time effective, portable, reliable and safe and provide insight into all physique traits, including both FM and FFM, are a priority.

Irrespective of the test chosen, all physique assessment tools carry with them some degree of assumption and measurement error. Having an appreciation of this helps to distinguish between measurement error and real changes in body composition (i.e. documented changes being greater than reported measurement error). While issues associated with equipment contributing to measurement error are often beyond the control of technicians, athlete presentation can also contribute to the error of repeat assessments. As such, factors such as time of day, hydration status and gastrointestinal tract contents should be standardised wherever possible; fasted early morning assessments may be the most reliable where practical. Minimising the error or noise associated with a test enhances its reliability, making it easier to identify small but potentially important changes. Reliability of measurement also influences the frequency of assessment. In general, physique assessments should not be undertaken any more regularly than every 4–8 weeks, depending on the individual athlete and their body composition goals.

When collecting data, the physical and emotional well-being of the athlete should remain a priority. Sensitivity should be shown to cultural beliefs and tradition. Procedures should be explained to those unfamiliar, with information provided in advance on what testing is to be undertaken, the reason for profiling, what measurements are to be taken and any specific requirements such as clothing to be worn. Where appropriate, consideration should be given to gender comparability between the technician and athlete, with privacy in data collection and reporting always assured. With this in mind, the establishment of electronic databases which not only provide a secure means of data collection but also automating reports that provide invaluable historical data as well as interpretation of existing results against previous assessments is encouraged. Finally, where resources permit, the collection of data in duplicate should be considered, enhancing the reliability of measurement.

Aligned with this, developing a better understanding of factors influencing the noise or error associated with body composition assessment tools will enable the development of protocols which afford a much greater resolution of measurement. Ultimately, this will help to create techniques and protocols that are able to detect small but potentially meaningful changes in body composition. Once established, this will also create an opportunity to have better resolution for assessing interventions (i.e. dietary, training) or unforeseen situations (i.e. injury, illness, detraining) proposed to influence body composition which ultimately will have application not only within the sports environment but also the wider community.

13.4 SUMMARY AND CONCLUSION

Body composition is just one of an array of "fitness traits" that may contribute to the overall success of an athlete with an impairment. As such, the association between physique traits and competitive success should not be overemphasised. However, the regular monitoring of body composition amongst athletic populations can offer insight into adaptations to training and/or dietary interventions as well as optimisation of body composition for specific sports and playing positions. An array of tools is available for the measurement of body composition, the test of choice being influenced by technical issues like safety, validity, precision and accuracy of measurement as well as practical issues such as availability, cost, portability, invasiveness, time effectiveness and technical expertise necessary to conduct the assessment. Among athletes with an impairment, consideration must also be given to the unique physique traits these individuals may possess. These factors considered together, the routine monitoring of body composition amongst athletes with an impairment continues to be undertaken with the use of surface anthropometry, although BIA, DXA and the BOD POD are becoming more popular as their accessibility increases. However, the unique physical characteristics of some athletes may violate the assumptions associated with some of these techniques or introduce substantial measurement error, making it difficult to identify small to moderate changes in physique traits.

Refinement of protocols such as the standardisation of how subjects present for assessment and an improved awareness of the limitations of each technique will allow more informed protocols to be developed. This will offer greater insight into acute and longitudinal monitoring of body composition changes and their importance to competitive success, as well as tailoring interventions that can assist in the appropriate manipulation of body composition. The continued monitoring of physique traits amongst athletes with an impairment will help facilitate the establishment of normative data across sports, positions and classifications, allowing greater insight into the importance of physique traits to competitive success in this athletic population.

REFERENCES

Abe, T., Kojima, K., Kearns, C.F., Yohena, H. and Fukuda, J. 2003. Whole body muscle hypertrophy from resistance training: distribution and total mass. *British Journal of Sports Medicine* 37:543–545.

Allison, G.T., Singer, K.P. and Marshall, R.N. 1995. The effect of body position on bioelectrical resistance in individuals with spinal cord injury. *Disability and Rehabilitation* 17:424–429.

Brozek, J., Grande, F., Anderson, J.T. and Keys, A. 1963. Densitometric analysis of body composition: Revision of some quantitative assumptions. *Annals of the New York Academy of Sciences* 110:113–140.

Buchholz, A.C., McGillivray, C.F. and Pencharz, P.B. 2003. The use of bioelectric impedance analysis to measure fluid compartments in subjects with chronic paraplegia. *Archives of Physical Medicine and Rehabilitation* 84:854–861.

Bulbulian, R., Johnson, R.E., Gruber, J.J. and Darabos, B. 1987. Body composition in paraplegic male athletes. *Medicine and Science in Sports and Exercise* 19:195–201.

Cisar, C.J., Housh, T.J., Johnson, G.O., Thorland, W.G. and Hughes, R.A. 1989. Validity of anthropometric equations for determination of changes in body composition in adult males during training. *Journal of Sports Medicine and Physical Fitness* 29:141–148.

Claessens, A.L., Hlatky, S., Lefevre, J. and Holdhaus, H. 1994. The role of anthropometric characteristics in modern pentathlon performance in female athletes. *Journal of Sports Sciences* 12:391–401.

Claessens, A.L., Lefevre, J., Beunen, G. and Malina, R.M. 1999. The contribution of anthropometric characteristics to performance scores in elite female gymnasts. *Journal of Sports Medicine and Physical Fitness* 39:355–360.

Clarys, J.P., Martin, A.D., Drinkwater, D.T. and Marfell-Jones, M.J. 1987. The skinfold: Myth and reality. *Journal of Sports Sciences* 5:3–33.

Clarys, J.P., Provyn, S. and Marfell-Jones, M.J. 2005. Cadaver studies and their impact on the understanding of human adiposity. *Ergonomics* 48:1445–1461.

Clasey, J.L. and Gater, D.R. Jr. 2005. A comparison of hydrostatic weighing and air displacement plethysmography in adults with spinal cord injury. *Archives of Physical Medicine and Rehabilitation* 86:2106–2113.

Davis, J.A., Dorado, S., Keays, K.A., Reigel, K.A., Valencia, K.S. and Pham, P.H. 2007. Reliability and validity of the lung volume measurement made by the BOD POD body composition system. *Clinical Physiology and Functional Imaging* 27:42–46.

Dempster, P. and Aitkens, S. 1995. A new air displacement method for the determination of human body composition. *Medicine and Science in Sports and Exercise* 27:1692–1697.

Dingley, A.A., Pyne, D.B. and Burkett, B. 2015. Relationships between propulsion and anthropometry in Paralympic swimmers. *International Journal of Sports Physiology and Performance* 10:978–985.

Dixon, C.B., Ramos, L., Fitzgerald, E., Reppert, D. and Andreacci, J.L. 2009. The effect of acute fluid consumption on measures of impedance and percent body fat estimated using segmental bioelectrical impedance analysis. *European Journal of Clinical Nutrition* 63:1115–1122.

Drinkwater, D.T. and Ross, W.D. 1980. Anthropometric fractionation of body mass. In *Kinanthropometry II*, eds. Ostyn, M., Beunen, G. and Simons, J. pp. 178–189. Baltimore: University Park Press.

Dunbar, C.C., Melahrinides, E., Michielli, D.W. and Kalinski, M.I. 1994. Effects of small errors in electrode placement on body composition assessment by bioelectrical impedance. *Research Quarterly for Exercise and Sport* 65:291–294.

Edwards, L.A., Bugaresti, J.M. and Buchholz, A.C. 2008. Visceral adipose tissue and the ratio of visceral to subcutaneous adipose tissue are greater in adults with than in those without spinal cord injury, despite matching waist circumferences. *American Journal of Clinical Nutrition* 87:600–607.

Eston, R.G., Rowlands, A.V., Charlesworth, S., Davies, A. and Hoppitt, T. 2005. Prediction of DXA-determined whole body fat from skinfolds: Importance of including skinfolds from the thigh and calf in young, healthy men and women. *European Journal of Clinical Nutrition* 59:695–702.

Fields, D.A., Higgins, P.B. and Hunter, G.R. 2004. Assessment of body composition by air-displacement plethysmography: Influence of body temperature and moisture. *Dynamic Medicine* 3:3.

Fields, D.A., Hunter, G.R. and Goran, M.I. 2000. Validation of the BOD POD with hydrostatic weighing: Influence of body clothing. *International Journal of Obesity and Related Metabolic Disorders* 24:200–205.

Forbes, G.B. 1999. Body composition: Overview. *Journal of Nutrition* 129(1S Suppl.):270S–272S.

Goosey-Tolfrey, V., Keil, M., Brooke-Wavell, K. and de Groot, S. 2016. A comparison of methods for the estimation of body composition in highly trained wheelchair games players. *International Journal of Sports Medicine* 37:799–806.

Higgins, P.B., Fields, D.A., Hunter, G.R. and Gower, B.A. 2001. Effect of scalp and facial hair on air displacement plethysmography estimates of percentage of body fat. *Obesity Research* 9:326–330.

Hind, K., Slater, G., Oldroyd, B. et al. 2018. Interpretation of dual-energy x-ray absorptiometry-derived body composition change in athletes: A review and recommendations for best practice. *Journal of Clinical Densitometry* 21:429–443.

Hume, P. and Marfell-Jones, M. 2008. The importance of accurate site location for skinfold measurement. *Journal of Sports Sciences* 26:1333–1340.

Ide, M., Ogata, H., Kobayashi, M., Tajima, F. and Hatada, K. 1994. Anthropometric features of wheelchair marathon race competitors with spinal cord injuries. *Paraplegia* 32:174–179.

Jaffrin, M.Y. 2009. Body composition determination by bioimpedance: An update. *Current Opinion in Clinical Nutrition and Metabolic Care* 12:482–486.

Jones, L.M., Goulding, A. and Gerrard, D.F. 1998. DEXA: A practical and accurate tool to demonstrate total and regional bone loss, lean tissue loss and fat mass gain in paraplegia. *Spinal Cord* 36:637–640.

Keil, M., Totosy de Zepetnek, J.O., Brooke-Wavell, K. and Goosey-Tolfrey, V.L. 2016. Measurement precision of body composition variables in elite wheelchair athletes, using dual-energy x-ray absorptiometry. *European Journal of Sport Sciences* 16:65–71.

Kelsey, J.L., Bachrach, L.K., Procter-Gray, E. et al. 2007. Risk factors for stress fracture among young female cross-country runners. *Medicine and Science in Sports and Exercise* 39:1457–1463.

Keogh, J.W., Hume, P.A., Pearson, S.N. and Mellow, P. 2007. Anthropometric dimensions of male powerlifters of varying body mass. *Journal of Sports Sciences* 25:1365–1376.

Kerr, A., Slater, G. and Byrne, N. 2017. Impact of food and fluid intake on technical and biological measurement error in body composition assessment methods in athletes. *British Journal of Nutrition* 117:591–601.

King, G.A., Fulkerson, B., Evans, M.J., Moreau, K.L., McLaughlin, J.E. and Thompson, D.L. 2006. Effect of clothing type on validity of air-displacement plethysmography. *Journal of Strength and Conditioning Research* 20:95–102.

Kocina, P. 1997. Body composition of spinal cord injured adults. *Sports Medicine* 23:48–60.

Koo, W.W.K., Hockman, E.M. and Hammami, M. 2004. Dual energy x-ray absorptiometry measurements in small subjects: Conditions affecting clinical measurements. *Journal of the American College of Nutrition* 23:212–219.

Kushner, R.F., Gudivaka, R. and Schoeller, D.A. 1996. Clinical characteristics influencing bioelectrical impedance analysis measurements. *American Journal of Clinical Nutrition* 64(Suppl.):423S–427S.

Kyle, U.G., Bosaeus, I., De Lorenzo, A.D. et al. 2004a. Bioelectrical impedance analysis – Part I: Review of principles and methods. *Clinical Nutrition* 23:1226–1243.

Kyle, U.G., Bosaeus, I., De Lorenzo, A.D. et al. 2004b. Bioelectrical impedance analysis – Part II: Utilization in clinical practice. *Clinical Nutrition* 23:1430–1453.

Lambrinoudaki, I., Georgiou, E., Douskas, G., Tsekes, G., Kyriakidis, M. and Proukakis, C. 1998. Body composition assessment by dual-energy x-ray absorptiometry: Comparison of prone and supine measurements. *Metabolism-Clinical and Experimental* 47:1379–1382.

Lands, L.C., Hornby, L., Hohenkerk, J.M. and Glorieux, F.H. 1996. Accuracy of measurements of small changes in soft-tissue mass by dual-energy x-ray absorptiometry. *Clinical and Investigative Medicine* 19:279–285.

Larsson, P. and Henriksson-Larsen, K. 2008. Body composition and performance in cross-country skiing. *International Journal of Sports Medicine* 29:971–975.

Lewiecki, E.M. 2005. Clinical applications of bone density testing for osteoporosis. *Minerva Medica* 96:317–330.

Lohman, M., Tallroth, K., Kettunen, J.A. and Marttinen, M.T. 2009. Reproducibility of dual-energy x-ray absorptiometry total and regional body composition measurements using different scanning positions and definitions of regions. *Metabolism-Clinical and Experimental* 58:1663–1668.

Lohman, T.G. 1981. Skinfolds and body density and their relation to body fatness: a review. *Human Biology* 53:181–225.

Madsen, O.R., Egsmose, C., Lorentzen, J.S., Lauridsen, U.B. and Sorensen, O.H. 1999. Influence of orthopaedic metal and high-density detection on body composition as assessed by dual-energy x-ray absorptiometry. *Clinical Physiology* 19:238–245.

Marfell-Jones, M., Clarys, J.P., Alewaeters, K., Martin, A.D. and Drinkwater, D.T. 2003. The hazards of whole body fat prediction in men and women. *Journal de Biometrie Humanaine et Anthropologie* 21:103–118.

Martin, A.D., Ross, W.D., Drinkwater, D.T. and Clarys, J.P. 1985. Prediction of body fat by skinfold caliper: Assumptions and cadaver evidence. *International Journal of Obesity* 9(Suppl. 1):31–39.

Mazess, R.B., Barden, H.S., Bisek, J.P. and Hanson, J. 1990. Dual-energy x-ray absorptiometry for total-body and regional bone-mineral and soft-tissue composition. *American Journal of Clinical Nutrition* 51:1106–1112.

Medeiros, R.M., Alves, E.S., Lemos, V.A. et al. 2016. Assessment of body composition and sport performance of Brazilian Paralympic swim team athletes. *Journal of Sport Rehabilitation* 25:364–370.

Meyer, N.L., Sundgot-Borgen, J., Lohman, T.G. et al. 2013. Body composition for health and performance: A survey of body composition assessment practice carried out by the Ad Hoc Research Working Group on Body Composition, Health and Performance under the auspices of the IOC Medical Commission. *British Journal of Sports Medicine* 47:1044–1053.

Minderico, C.S., Silva, A.M., Fields, D.A. et al. 2008. Changes in thoracic gas volume with air-displacement plethysmography after a weight loss program in overweight and obese women. *European Journal of Clinical Nutrition* 62:444–450.

Miyahara, K., Wang, D.H., Mori, K. et al. 2008. Effect of sports activity on bone mineral density in wheelchair athletes. *Journal of Bone and Mineral Metabolism* 26:101–106.

Mojtahedi, M.C., Valentine, R.J. and Evans, E.M. 2009. Body composition assessment in athletes with spinal cord injury: comparison of field methods with dual-energy x-ray absorptiometry. *Spinal Cord* 47:698–704.

Mueller, W.H. and Stallones, L. 1981. Anatomical distribution of subcutaneous fat: Skinfold site choice and construction of indices. *Human Biology* 53:321–335.

Nana, A., Slater, G.J., Hopkins, W.G. and Burke, L.M. 2012. Effects of daily activities on dual-energy x-ray absorptiometry measurements of body composition in active people. *Medicine and Science in Sports and Exercise* 44:180–189.

National Institutes of Health. 1996. NIH Consensus statement. Bioelectrical impedance analysis in body composition measurement. National Institutes of Health Technology Assessment Conference Statement. December 12-14, 1994. *Nutrition* 12:749–762.

Olds, T. 2001. The evolution of physique in male rugby union players in the twentieth century. *Journal of Sports Sciences* 19:253–262.

Peeters, M.W. and Claessens, A.L. 2011. Effect of different swim caps on the assessment of body volume and percentage body fat by air displacement plethysmography. *Journal of Sports Sciences* 29:191–196.

Pichard, C., Kyle, U.G., Gremion, G., Gerbase, M. and Slosman, D.O. 1997. Body composition by x-ray absorptiometry and bioelectrical impedance in female runners. *Medicine and Science in Sports and Exercise* 29:1527–1534.

Pietrobelli, A., Formica, C., Wang, Z. and Heymsfield, S.B. 1996. Dual-energy x-ray absorptiometry body composition model: Review of physical concepts. *American Journal of Physiology* 271(6 Pt 1):E941–951.

Prouteau, S., Ducher, G., Nanyan, P., Lemineur, G., Benhamou, L. and Courteix, D. 2004. Fractal analysis of bone texture: A screening tool for stress fracture risk? *European Journal of Clinical Investigations* 34:137–142.

Reid, I.R., Evans, M.C. and Ames, R. 1992. Relationships between upper-arm anthropometry and soft-tissue composition in postmenopausal women. *American Journal of Clinical Nutrition* 56:463–466.

Roche, A.F. 1996. Anthropometry and ultrasound. In *Human Body Composition*, eds. Roche, A.F., Heymsfield, S.B. and Lohman, T.G. pp. 167–190. Champaign, IL: Human Kinetics.

Rosendale, R.P. and Bartok, C.J. 2012. Air-displacement plethysmography for the measurement of body composition in children aged 6–48 months. *Pediatric Research* 71:299–304.

Roubenoff, R., Kehayias, J.J., Dawson-Hughes, B. and Heymsfield, S.B. 1993. Use of dual-energy x-ray absorptiometry in body-composition studies: not yet a "gold standard". *American Journal of Clinical Nutrition* 58:589–591.

Ruiz, L., Colley, J.R. and Hamilton, P.J. 1971. Measurement of triceps skinfold thickness. An investigation of sources of variation. *British Journal of Preventive and Social Medicine* 25:165–167.

Saunders, M.J., Blevins, J.E. and Broeder, C.E. 1998. Effects of hydration changes on bioelectrical impedance in endurance trained individuals. *Medicine and Science in Sports and Exercise* 30:885–892.

Shephard, R.J. 1998. Science and medicine of rowing: A review. *Journal of Sports Sciences* 16:603–620.

Siders, W.A., Lukaski, H.C. and Bolonchuk, W.W. 1993. Relationships among swimming performance, body composition and somatotype in competitive collegiate swimmers. *Journal of Sports Medicine and Physical Fitness* 33:166–171.

Silva, A.M., Fields, D.A., Quiterio, A.L. and Sardinha, L.B. 2009. Are skinfold-based models accurate and suitable for assessing changes in body composition in highly trained athletes?. *Journal of Strength and Conditioning Research* 23:1688–1696.

Siri, W.E. 1993. Body composition from fluid spaces and density: Analysis of methods. 1961. *Nutrition* 9:480–491.

Stewart, A.D. and Hannan, W.J. 2000. Prediction of fat and fat-free mass in male athletes using dual x-ray absorptiometry as the reference method. *Journal of Sports Sciences* 18:263–274.

Stewart, A.D., Marfell-Jones, M.J., Olds, T. and de Ridder, J.H. 2011. *International Standards for Anthropometric Assessment*. Wellington, New Zealand: The International Society for the Advancement of Kinanthropometry.

Stoggl, T., Enqvist, J., Muller, E. and Holmberg, H.C. 2010. Relationships between body composition, body dimensions, and peak speed in cross-country sprint skiing. *Journal of Sports Sciences* 28:161–169.

Strauss, B.J., Gibson, P.R., Stroud, D.B., Borovnicar, D.J., Xiong, D.W. and Keogh, J. 2000. Total body dual x-ray absorptiometry is a good measure of both fat mass and fat-free mass in liver cirrhosis compared to "gold-standard" techniques. Melbourne Liver Group. *Annals of the New York Academy of Sciences* 904:55–62.

Sutton, L., Wallace, J., Goosey-Tolfrey, V., Scott, M. and Reilly, T. 2009. Body composition of female wheelchair athletes. *International Journal of Sports Medicine* 30:259–265.

Tegenkamp, M.H., Clark, R.R., Schoeller, D.A. and Landry, G.L. 2011. Effects of covert subject actions on percent body fat by air-displacement plethsymography. *Journal of Strength and Conditioning Research* 25:2010–2017.

Utter, A.C., Goss, F.L., Swan, P.D., Harris, G.S., Robertson, R.J. and Trone, G.A. 2003. Evaluation of air displacement for assessing body composition of collegiate wrestlers. *Medicine and Science in Sports and Exercise* 35:500–505.

van Marken Lichtenbelt, W.D., Hartgens, F., Vollaard, N.B., Ebbing, S. and Kuipers, H. 2004. Body composition changes in bodybuilders: A method comparison. *Medicine and Science in Sports and Exercise* 36:490–497.

Vescovi, J.D., Zimmerman, S.L., Miller, W.C. and Fernhall, B. 2002. Effects of clothing on accuracy and reliability of air displacement plethysmography. *Medicine and Science in Sports and Exercise* 34:282–285.

Vilaca, K.H., Ferriolli, E., Lima, N.K., Paula, F.J. and Moriguti, J.C. 2009. Effect of fluid and food intake on the body composition evaluation of elderly persons. *The Journal of Nutrition, Health and Aging* 13:183–186.

White, A.T. and Johnson, S.C. 1991. Physiological comparison of international, national and regional alpine skiers. *International Journal of Sports Medicine* 12:374–378.

Willems, A., Paulson, T.A., Keil, M., Brooke-Wavell, K. and Goosey-Tolfrey, V.L. 2015. Dual-energy x-ray absorptiometry, skinfold thickness, and waist circumference for assessing body composition in ambulant and non-ambulant wheelchair games players. *Frontiers in Physiology* 6:356.

Wilmore, J.H., Girandola, R.N. and Moody, D.L. 1970. Validity of skinfold and girth assessment for predicting alterations in body composition. *Journal of Applied Physiology* 29:313–317.

Withers, R.T., Whittingham, N.O., Norton, K.I., La Forgia, J., Ellis, M.W. and Crockett, A. 1987. Relative body fat and anthropometric prediction of body density of female athletes. *European Journal of Applied Physiology and Occupational Physiology* 56:169–180.

14 Use of Supplements in Athletes with an Impairment

Claudio Perret and Greg Shaw

CONTENTS

14.1 INTRODUCTION

There seems to be a high prevalence of supplement use in the elite sports community not only in Olympic but also in Paralympic sports. The first study reporting supplement use in Paralympic sports was performed during the Paralympic Games held in Athens 2004 (Tsitsimpikou et al. 2009), where 64% of athletes tested for doping used supplements or medication. Similar results were found in more recent international (Graham-Paulson et al. 2015) and national studies (Flueck and Perret 2017; Madden et al. 2018), with a prevalence of 58 to 91% supplement use, depending on the definition of a supplement.

In general, the reasons athletes ingest supplements include performance enhancement, supporting exercise recovery, providing energy, enhancing the immune system and general health, or treating an injury (Graham-Paulson et al. 2015; Maughan et al. 2007). Although supplements were already widely applied in Paralympic sports, there is a lack of information tailored to the special needs of this unique sports population concerning correct and specific application, risks and benefits of supplement use (Flueck and Perret 2017; Graham-Paulson et al. 2015). In this context, one has to take into account the potential physiological differences between able-bodied and Paralympic athletes (as outlined in previous chapters). In the case of a spinal cord injury (SCI), for example, the most important factors which might have an impact on nutrition and supplementation include a prolonged gastrointestinal transition time (Fynne et al. 2012; Krogh et al. 2000), a reduced resting energy expenditure (Felleiter et al. 2017; Perret and Stoffel-Kurt 2011), changes in body composition (Spungen et al. 2000) and muscle fibre type distribution (Schantz et al. 1997), as well as thermoregulatory restrictions (Bhambhani 2002). Additionally, exercise in individuals with a SCI is limited to the upper body, which reduces potential total energy expenditure. Of course, the impact of these factors depends on the level and severity of the lesion and has to be assessed on an individual basis for each athlete. Moreover, other factors such as stress or medication use, in combination with the autonomic disruption of the gastrointestinal system, may negatively influence digestion, resorption, absorption and excretion of nutrients (see Chapter 12).

This chapter will discuss different aspects of supplement use by Paralympic athletes. Questions about whether to take supplements, the potential benefits and risks and the potential negative health implications, as well as how and which supplements might be used and useful, will be elucidated.

14.2 FRAMEWORK TO DECIDE WHETHER TO TAKE A SUPPLEMENT

14.2.1 What Is a Supplement?

"Dietary supplement" is a broad term with numerous definitions and is extremely fluid, influenced by reason for use, mode of delivery and the international regulatory framework. A universal definition of dietary supplement can be problematic. What is defined as a dietary supplement changes from country to country, with most countries' definitions focusing on the form, purpose and regulation of specific health claims (Dietary Supplement Health and Education Act (DHSEA) of 1994; Directive 2002/46/EC of the European Parliament and the Council of The European Union 2002). More recently the International Olympic Committee (IOC) has defined a dietary supplement as "a food, food component, nutrient or non-food compound that is purposefully ingested in addition to the habitually consumed diet with the aim of achieving a specific health and/or performance benefit." Additionally, the IOC recognises that the form of dietary supplements ranges from functional foods bought in supermarkets to complex multi-ingredient products pharmaceutically designed for a specific health or performance outcome (Maughan et al. 2018). While it can be argued that intravascular and intramuscular injection of nutrients should be classified as a medical procedure rather than as a dietary supplement, it is noted that athletes report self-administration of injectable dietary nutrients as a way of supplementing dietary sources (Corrigan and Kazlauskas 2003). For example, recently the use of iron infusions has become a recommended therapy for the correction of anaemia in athletic populations, under the supervision of a medical professional (Clénin et al. 2015). However, Paralympic athletes should be aware that any injection or infusion is governed by the World Anti-Doping Agency (WADA) "CODE" and should only be managed by a qualified sports physician, even if the injection is to correct a nutrition deficiency.

One system developed to classify supplements based on the strength of the evidence for effectiveness when used according to best practise is the Sport Supplement Framework of the Australian Institute of Sport (AIS, Burke and Cato 2015). This framework suggests a categorisation system to divide dietary supplements into a series of groups (A, B, C and D), based on the level of scientific evidence available for performance enhancement and the relative risk of a dietary supplement containing a banned substance.

Ultimately an athlete needs to know what constitutes a dietary supplement, the form in which ingestion is most effective at improving performance or health, and the relative risk of that form of supplemental nutrient delivery leading to a negative performance outcome. They should employ a detailed decision-making process that entails first discussion with their coach, second discussion with a sports nutrition expert and finally a risk-benefit analysis performed around "Should I take this supplement?"

14.2.2 Framework for Decision-Making

Dietary supplements can appear a simple solution to a complicated problem. That is, consume supplement "A" and perform better in task "B." However, what on the surface often appears a simple decision is one that athletes should devote significant time and effort towards. Issues such as contaminated supplements – with illegal and/or WADA-banned ingredients (Geyer et al. 2004; Thomas et al. 2010), adverse or toxic reactions (Navarro et al. 2017) – and the variability in individual response to standardised supplement protocols should all be considered (Burke 2017). Recently, a paper by an IOC working group on the use of dietary supplements outlined a detailed decision-making process for athletes considering taking a dietary supplement for the first time (Maughan et al. 2018). The authors point out that there is often efficacious evidence that supports the ergogenic effects of a small number of dietary nutrients. However, the effectiveness of these nutrients is often contextual to the gender, size and genotype of the athlete undertaking an exercise task of varying duration, modality and intensity (Maughan et al. 2018). Additionally, they discussed the hierarchy of evidence athletes might use to justify taking a dietary supplement to enhance performance. Although this detail is highly beneficial for elite athletes, it is often difficult for athletes with an impairment, particularly one that impacts cognitive function, to make these decisions independently. It is therefore extremely important that these athletes don't make supplement decisions without the support and knowledge of a sports nutrition or medicine expert.

An even simpler construct of questions could be:

- Could this supplement negatively affect my health?
- Could this supplement possibly be contaminated?
- Could this supplement work for me?

Below we will discuss these questions and how they may be contextualised for Para athletes.

14.3 POTENTIAL BENEFITS OF DIETARY SUPPLEMENTS

14.3.1 Convenience

The simple delivery of nutrients in a convenient form or specific amount, using avenues that have low food safety requirements, a pleasant taste and long shelf life can be both practical and nutritionally beneficial to athletes (Burke and Cato 2015). "Sports foods" provide convenience, and in certain circumstances may have specific ergogenic benefits over real foods. For example, a protein powder with water added, consumed after a gym session on the way to work could provide a protein source that is more convenient and compact than food sources such as dairy. Dietary supplements may also provide valuable micronutrients to athletes whose dietary intake is suboptimal due to personal preference, a restricted energy budget (Lun et al. 2009) or as a consequence of altered requirements. While dietary supplementation can provide convenience and a valuable source of specific nutrients, Para athletes should be encouraged to meet their nutritional requirements primarily from whole food sources first and foremost – laziness or poor organisation are no justification for using supplements of any type.

14.3.2 Evidence for Use

The number of dietary supplements that have scientific evidence for effective performance enhancement is small. This is in contrast to the vast number of supplements with proposed "potential efficacy for use in sporting situations" but for which the scientific evidence is either unavailable or fails to show benefits (Burke and Cato 2015). It is important that Paralympic athletes realise that "potential efficacy" does not always guarantee performance enhancement. It may also be the case that dietary supplementation negatively impacts athletic training and performance (Ristow et al. 2009).

The effectiveness of most dietary supplements is often judged on its physiological efficacy for use. Whether it alters, increases or enhances a physiological process which may potentially transfer to an enhancement in performance is often the sole basis for an athlete's decision to use. Although proof of efficacy is essential before research can move onto demonstrating the effectiveness of a dietary supplement in a range of sporting situations, efficacy should not be substituted for evidence that the dietary supplement will work in all individual cases. An example of this is creatine. This dietary supplement took up to 10 years to demonstrate clear situations for performance improvement, even though the efficacy of ingestion and enhanced storage was shown in 1992 (Harris et al. 1992). However, anecdotal reports of British track athletes using dietary creatine supplements surfaced as early as the 1992 Barcelona Olympics. This was simultaneous with the outlining of the theory for use and well before the scientific demonstration of effective use occurred. It is important that Para athletes pay particular attention to the situations and protocols in which specific dietary supplements have been demonstrated beneficial. As pointed out in Section 14.5, the evidence to support the effectiveness of dietary supplements in Para athletes is small. Therefore, detailed discussion needs to be held among coaches, athletes and professionals knowledgeable in the physiology of Para athletes to ensure the nutrient or chemical in question will be absorbed, integrated and metabolised in a similar manner to the subjects studied with that supplement. It also illustrates the pitfalls Para athletes can face when products are brought to market before substantial evidence is available regarding the ideal supplement dosing protocols, the activities which may benefit the most from the product, and most importantly whether it has the same effect in Para athletes.

14.3.3 Individualisation

The distinction between enhanced performance and improved physiological capacity has been presented as an important concept for elite athletes to understand with respect to dietary supplement effectiveness (Hobson et al. 2012). There are some supplements which are most beneficial in improving training capacity and adaptations (such as creatine), whereas there are others for which the research has been confined to specific use in competition (such as sodium bicarbonate). Furthermore, there must be consideration of situations where repeated use may result in a loss of effectiveness or adverse effects, such as the balance between potential benefits of caffeine use and the impact of disrupted sleep over the duration of a swim or athletics meet. Finally, discussion should focus on whether individualising supplement protocols to an athlete's genetics, physiology and race pacing could further improve the effectiveness of supplements (Siegler et al. 2016; Womack et al. 2012). Paralympic athletes have unique physiologies, influenced mostly by individual phenotype but also medication and the nature and degree of impairment. This means that any dietary supplement ingested with the purpose of improving performance should be individualised to the athlete, manipulating the dose, timing and form to optimise its potential ergogenic effects. This should be done through detailed consultation among the coach, athlete and sport science and medicine support staff to ensure all areas are considered equally in planning supplement use.

COMMENTARY BOX 14.1

COACH'S INSIGHT: What sports nutrition practises have had the biggest impact on the training capability or performance of your athletes?

Fundamental is for athletes (and coaches) to understand that: 1. food is fuel; 2. that performance and recovery are impacted by the quality, quantity and timing of fuel that you put in your body; and 3. that athletes must take responsibility for this.

The "food first" philosophy is also important. Ensuring that athletes' nutritional needs are met as far as possible via the daily diet, with supplements only being added if and when necessary. Regular monitoring (such as via blood work and check-in with the sport nutrition professional) helps with this.

If these two basic concepts ("food is fuel" and "food first") are not understood and fully embraced, then there is no point considering the "optional extras" that can further enhance performance. Athletes must get the basics right first.

Obviously, understanding the impact of adequate hydration and knowing how to monitor and maintain this is also important.

Jenni Banks, wheelchair racing and hand cycling coach of 33 years, coach of Paralympic medallists in both sports

14.4 POTENTIAL RISKS AND CONCERNS WHEN USING SUPPLEMENTS

The recently published consensus statement of the IOC recommends following a strict risk-benefit analysis when considering using a supplement (Maughan et al. 2018). At the same time, authors warn of potential risks and harm concerning health, performance and livelihood, as well as reputation (e.g. antidoping rule violation), when supplements were inadequately applied. The following paragraphs will critically discuss such issues in more detail.

14.4.1 Expense

A recently published report of Ronis and colleagues (2018) revealed that over 70% of Americans take dietary supplements on a daily basis, which leads to gross earnings of over US$28 billion. This example underlines that the dietary supplement industry is a big business nowadays. Athletes spend considerable amounts of money on dietary supplements (Brill and Keane 1994; Burke and Cox 2010; Slater et al. 2003; Tian et al. 2009). A study of university athletes in Singapore (Tian et al. 2009) revealed that average monthly expenses for supplements were S$34. However, some athletes spent up to S$150 per month. In an earlier study, one athlete was even reported to spend US$870 a month (Slater et al. 2003). This data is concerning in that some athletes spend more money on dietary supplements than whole foods, despite the fact that real foods may be often less expensive and contain similar concentrations of key nutrients. In a study of unemployed Sri Lankan athletes, about two-thirds purchased dietary supplements despite a limited financial situation (de Silva et al. 2010). An earlier study reported only minimal cost concerns of athletes purchasing dietary supplements (Baylis et al. 2001). These findings underline the need for proper information to be accessible, and education resources available to athletes, in order to increase nutritional awareness and knowledge (Scaramella et al. 2018) and avoid unnecessary expenses.

14.4.2 Potential Negative Health Implications and Consequences of Supplement Use

Little thought is given by athletes to the negative health consequences the ingestion of dietary supplements may cause. There are numerous reports of all levels of athletes suffering significant health issues associated with the use of supposedly innocuous dietary supplements. One has to keep in mind that even the ingestion of herbal supplements, often declared as natural and thought to be harmless substances, is not without risks. A typical example is extracts containing ephedrine, a substance often incorporated into weight-loss supplements (Shekelle et al. 2003). Supplementation with ephedrine or ephedrine-containing products increased the risk of side effects 2.2–3.6-fold, including heart palpitations, autonomic hyperactivity, psychiatric and gastrointestinal symptoms (Shekelle et al. 2003). Further, a recently published review reported that 20% of drug-induced liver injuries were associated with dietary supplement ingestion (Navarro et al. 2017). A typical example for changes of drug pharmacokinetics is the parallel ingestion of grapefruit juice and certain medications (Bailey and Dresser 2004), which are metabolised by the same enzymatic system. Similarly, the excessive intake of vitamins such as vitamin E (Miller et al. 2005) or vitamin A (Melhus et al. 1998) can lead to serious problems. The latter was associated with reduced bone mineral density and increased risk for hip fractures. A study from Suzic Lazic and colleagues (2011) showed that Serbian Paralympic athletes either ingest multiple sources of the same minerals or ingredients or use detrimental combinations of dietary supplements and medication. It seems that many athletes seldom care about potential adverse effects or interactions (Baylis et al. 2001; Corrigan and Kazlauskas 2003; Slater et al. 2003; Suzic Lazic et al. 2011; Tscholl et al. 2010). However, athletes should be aware of the fact that the worst-case scenario of an incorrect supplementation might be severe adverse effects or health problems. Further, there exist situations where potential benefits of a supplement might be reduced or masked by an interaction. There was one study reporting an elimination of the ergogenic effect of creatine when it was ingested concomitantly with caffeine (Vandenberghe et al. 1996). However, in such situations, simply separating the timing of ingestion might help to solve this problem.

Another commonly reported effect was gastrointestinal problems. Flueck et al. (2014) reported 5 out of 9 athletes complained about gastrointestinal symptoms such as diarrhoea after sodium citrate ingestion. Anecdotal evidence suggests tart cherry juice may also have a laxative effect, especially in athletes with a SCI, and the documented impact of dietary nitrate supplements (i.e. beetroot juice) on reducing blood pressure (Burke and Cato 2015) could cause adverse effects in athletes whose blood pressure regulation is disrupted, such as athletes with quadriplegia. Graham-Paulson et al. (2016b) reported adverse effects such as increased spasticity and nausea in 5 of 12 wheelchair rugby players after the ingestion of 4 mg/kg caffeine. Since a high proportion of wheelchair athletes suffer from gastrointestinal complications as a consequence of their impairment (Fynne et al. 2012; Krogh et al. 2000), it seems obvious that this population is more prone to adverse effects of this type. A reduction of the dosage (e.g. related to mg/kg muscle mass instead of mg/kg body mass) or a change in the timing might help to solve these problems. These assumptions are supported by results of two studies in wheelchair athletes. In athletes with quadriplegia, higher plasma caffeine concentrations were reached after the same relative (mg/kg) caffeine dose was ingested compared to able-bodied athletes or those with paraplegia (Flueck et al. 2015). Another investigation showed, at least in some cases, longer times to peak plasma caffeine after ingestion in wheelchair rugby athletes compared to able-bodied athletes (Graham-Paulson et al. 2017). Additionally, the fitness level of an athlete might impact supplement effectiveness (Perret and Flueck 2016), an assumption supported by two creatine monohydrate studies. An ergogenic effect in patients with a SCI was found after creatine monohydrate ingestion (Jacobs et al. 2002), whereas no benefits were found in wheelchair racing athletes (Perret et al. 2006). At present, it seems that at least in Paralympic sport, individual adaptations in terms of timing, dosage and potential risks and side effects is evident.

14.4.3 Contamination and Doping Concerns

Athletes have long been warned about the potential risk of supplements being contaminated with WADA-prohibited substances. Today, numerous education programs exist to encourage athletes to scrutinise ingredients, manufacturing processes and claims of dietary supplements to ensure they are not a risk of consuming a banned substance (Supplement 411, AIS Sport Supplement Framework, UKAD 100% Me). Even though these education programs exist and evidence of the breadth of contamination has been known for well over a decade (Geyer et al. 2004), a large proportion of the world wide annual antidoping rule violations (ADRVs) are associated with dietary supplements. Although it can be argued that this is the fault of manufacturers who often deliberately contaminate their products with banned substances (Geyer et al. 2008), the responsibility for ADRV falls with the athlete (strict liability). Therefore, athletes taking dietary supplements should do so only from sources that are the lowest risk possible. Programs currently exist across the world to help athletes choose products that have been independently tested for banned substances prior to be available for sale (e.g. Informed Sport, NSF Certified for Sport and BSCG Certified Drug Free). These companies provide certification that a product has been tested for a defined number of banned substances prior to going on sale, and have been shown effective (Judkins et al. 2010), but can only reduce the risk, not remove it completely (Maughan et al. 2018). Paralympic athletes are strongly encouraged to only use products that have gone through a third-party testing program to help ensure they are using products that are the lowest risk possible. As a secondary check, they should always discuss the product they intend using for supplemental nutrients or ingredients with a sports nutrition or medicine professional prior to consumption. This will help reduce the risk of contamination to an acceptably small level and ensure an ADRV is not the result of dietary supplement use.

COMMENTARY BOX 14.2

ATHLETE'S INSIGHT: What do you think is the most important thing a sports nutrition practitioner can do to assist you? That is, do you have any specific recommendations or suggestions to young, upcoming sports nutrition practitioners who want to work with Para athletes?

> You don't need any of the fancy stuff which is on the market (products). They need to focus on the effects of what foods you consume. Understand what your body needs and what foods supply this, and also what the effect consuming the wrong stuff has on your system.

Charl Parkin, Swimming and Triathlon, Motor Neurone Disease

14.5 SUPPLEMENT USE IN PARALYMPIC ATHLETES

Common supplements used by Paralympic athletes include multivitamins, sports drinks, protein and carbohydrates (Flueck and Perret 2017; Graham-Paulson et al. 2015; Madden et al. 2018), which is similar to able-bodied athletes (Maughan et al. 2007). The goals of supplementation vary widely and include performance enhancement, supporting exercise recovery, providing energy, enhancing the immune system and general health or treating an injury (Graham-Paulson et al. 2015; Maughan et al. 2007).

A substantial body of work exists for supplementation and exercise performance in able-bodied athletes, whereas data for Paralympic athletes is limited, with often controversial results (Perret and Flueck 2016). These differences might be partially explained by the physiological differences outlined above. At present, a small number of peer-reviewed studies in wheelchair athletes are available and will be discussed below and are summarised in more detail in Table 14.1.

14.5.1 Carbohydrate

The use of 600 mL of a concentrated (11%) carbohydrate solution 20 minutes before exercise showed a tendency for better wheelchair racing performance compared to a 4% solution (Spendiff and Campbell 2005). The appropriate use of carbohydrate requires consideration of the specific Para athlete's exercising conditions, such as resting (Felleiter et al. 2017; Perret and Stoffel-Kurt 2011) and exercising energy expenditure (Abel et al. 2003, 2008). More detailed recommendations for carbohydrate intake in Para athletes can be found in a recently published article by Scaramella and colleagues (2018) and in Chapter 3.

14.5.2 Creatine Monohydrate

There exists sufficient evidence for ergogenic effects of a well-directed creatine supplementation protocol in certain able-bodied athletes (Buford et al. 2007). However, a placebo-controlled, double-blind and crossover designed investigation

TABLE 14.1
Identified Studies Dealing with Supplement Use and Performance in Athletes with a Spinal Cord Injury

Reference	Sport/Participants	Supplement	Supplement Dosage	Exercise Protocol	Performance Outcome
Spendiff and Campbell (2005)	Wheelchair athletics, 8 male paraplegic athletes	Carbohydrates	600 mL of a 4% and 11% carbohydrate solution 20 min before exercise	Wheelchair exercise at 65% of VO_{2peak} for 1 h followed by a 20-min time trial performance test	Tendency for greater performance distance and power output, higher blood glucose concentrations, respiratory exchange ratios and significantly lower free fatty acid concentrations during the 11% carbohydrate trial compared to 4% carbohydrate trial
Perret et al. (2006)	Wheelchair athletics, 6 (4 male, 2 female) competitive athletes	Creatine monohydrate	4 × 5 g/day for 6 days	800-m time trial	No significant differences between creatine and placebo supplementation in 800 m performance, rate of perceived exertion, lactate concentrations, heart rate and body mass
Jacobs et al. (2002)	16 untrained chronic patients with a tetraplegia	Creatine monohydrate	4 × 5 g/day for 7 days	VO_{2peak} test on an arm-crank ergometer	Significant increase in VO_{2peak} (+17.4%) and peak power (+6.7%) compared to placebo treatment
Flueck et al. (2016)	20 male wheelchair athletes from rugby (n = 14), basketball (n = 4), table tennis (n = 2)	Vitamin D	6,000 IU/d during 12 weeks	Isokinetic dynamometer test; Wingate test on an arm-crank ergometer	Significant increase (10.9%) in isokinetic dynamometer strength, but only in the nondominant arm. No changes in Wingate test performance

(*Continued*)

TABLE 14.1 (*Continued*)
Identified Studies Dealing with Supplement Use and Performance in Athletes with a Spinal Cord Injury

Reference	Sport/Participants	Supplement	Supplement Dosage	Exercise Protocol	Performance Outcome
Pritchett et al. (2019)	Male and female wheelchair rugby (n = 25) and wheelchair athletics (n = 10) competitive athletes	Vitamin D	Depending on initial vitamin D status between 35,000 and 50,000 IU/wk during 4 or 8 weeks, respectively. Thereafter, maintenance dose of 15,000 IU/wk. Total supplementation time 12–16 weeks	Handgrip strength and 20-m wheelchair sprint performance	62% of participants increased handgrip strength; no changes in 20-m sprint times
Graham-Paulson et al. (2016b)	Wheelchair rugby, 12 male wheelchair rugby players	Caffeine	4 mg/kg body mass 70 min before exercise	Four sets of 4-min upper body push exercise and 3 sets of 3 × 20-m sprints	Average sprint times were significantly faster compared to placebo and participants pushed significantly further during the first set of 4-min push exercise
Graham-Paulson et al. (2016a)	11 recreationally active, healthy males	Caffeine	4 mg/kg 50 min before warm-up	5 min standardised warm-up, 30 min hand cycling at 65% VO_{2peak}, 5 min rest, 10 km hand cycling time trial	No change in 10 km time trial hand cycling performance
Graham-Paulson et al. (2018)	One elite Para triathlete	Caffeine	4 trials with 0, 2, 4 and 6 mg/kg 45 min before exercise	20-km hand cycling time trial performance	1.5 to 2.7% performance improvement compared to placebo

(*Continued*)

TABLE 14.1 (*Continued*)
Identified Studies Dealing with Supplement Use and Performance in Athletes with a Spinal Cord Injury

Reference	Sport/Participants	Supplement	Supplement Dosage	Exercise Protocol	Performance Outcome
Flueck et al. (2015)	Arm crank exercise in trained paraplegic (P, n = 10), quadriplegic (T; n = 7) and able-bodied (AB; n = 17) participants	Caffeine	6 mg/kg body mass 1 h prior test	3 min all out arm cranking	Significantly increased average power over first 30 s and 60 s in P but not in T nor AB compared to placebo. Tendency for increased peak power in AB (+46 W; $p = 0.10$) and P (+21 W; $p = 0.17$) but not in T (+2 W; $p = 0.49$). Plasma caffeine significantly increased in all groups, whereas epinephrine significantly increased only in AB and P. Norepinephrine significantly increased only in AB
Flueck et al. (2014)	Wheelchair athletics, 9 (6 male, 3 female) elite athletes	Caffeine	6 mg/kg body mass 1 h prior test	1,500-m time trial	Significantly higher maximal lactate concentrations compared to placebo. No significant difference in 1,500-m performance
	Wheelchair athletics, 9 (6 male, 3 women) elite athletes	Caffeine & sodium citrate	6 mg/kg body mass caffeine 1 h prior exercise; 0.5 g/kg body mass sodium citrate 120–90 min prior exercise	1,500-m time trial	Significantly higher maximal lactate concentrations compared to placebo. No significant difference in 1,500-m performance
	Wheelchair athletics, 9 (6 male, 3 women) elite athletes	Sodium citrate	0.5 g/kg body mass 120–90 min before exercise	1,500-m time trial	Significantly increased blood pH and bicarbonate concentrations compared to placebo. No significant difference in 1,500-m performance. 5 out of 9 athletes complained about side effects under supplementation

with wheelchair racing athletes did not show beneficial effects on 800 m race time (Perret et al. 2006). Authors explained these results mainly by differences in fibre type distribution of the muscles involved in upper body exercise. Interestingly, a study in untrained (VO_{2peak} of 11 ± 4 mL/min/kg) patients with quadriplegia revealed a significant increase in peak power output (+6.7%) after creatine supplementation (Jacobs et al. 2002). These findings lead to the assumption that training status might play a role on effectiveness of supplement use.

14.5.3 Vitamin D

Vitamin D is involved in various biological processes and influences bone health, skeletal muscle function and metabolism (Scaramella et al. 2018). Thus, it seems important to avoid deficiency not only in view of athletic performance but also from a general health perspective. Para athletes are at higher risk for a vitamin D deficiency due to numerous reasons related to their impairments (Scaramella et al. 2018). Although a well-known issue, vitamin D deficiency is still a common problem in elite wheelchair athletes (Flueck et al. 2016; Pritchett et al. 2016), especially during winter months and in indoor sports. For more detailed information concerning this issue, please refer to Chapter 6.

A study with vitamin D-deficient wheelchair basketball and wheelchair rugby players reported that a daily vitamin D dosage of 6,000 IU over 12 weeks was sufficient to reach optimal blood plasma levels, whereas no significant increase in Wingate performance or isokinetic dynamometer strength in the dominant arm was found (Flueck et al. 2016). In contrast, a significant increase in isokinetic dynamometer strength of the nondominant arm was found. Pritchett and colleagues (2019) were able to show increased handgrip strength in elite athletes with a SCI after a 12–16 week supplementation period, whereas 20-m sprint performance did not change. Dependent on the initial vitamin D status, a supplementation dose of 35,000 or 50,000 IU/wk was used for 4 or 8 weeks, respectively. Thereafter, a maintenance dose of 15,000 IU/wk was ingested. Having a closer look at the supplementation dosage of the two studies mentioned above, it seems remarkable that considerably higher doses seem to be necessary to reach adequate vitamin D levels compared to the recommended dietary intake of 400–800 IU/d (Pilz et al. 2018).

14.5.4 Caffeine

Caffeine is a well-known and often-investigated stimulant, which showed ergogenic potential in several studies performed with able-bodied athletes (for review, see Spriet 2014). Common doses range from 1.5 to 6 mg/kg body mass and were usually ingested 60 min pre-exercise. In able-bodied athletes, caffeine showed positive effects on short-term as well as endurance exercise (Spriet 2014). In contrast, Paralympic athletes seem to benefit more for short-term (up to few minutes) or sprint exercise (Flueck et al. 2015; Graham-Paulson et al. 2016b), since a study on a 10-km hand cycling time-trial failed to show significant effects on endurance performance (Graham-Paulson et al. 2016a). Authors explained the lack of hand cycling improvements by the smaller active muscle mass, elevated blood lactate concentrations or the participants' training status. However, a single case study with a Para triathlete showed an increased hand cycling time trial performance (Graham-Paulson et al. 2018). Indicated reasons for this performance enhancement were a greater arousal and an increased power output for a given rating of perceived exertion. Based on the present data, it seems that at least some Para athletes benefit from caffeine ingestion, preferentially during short-term exercise. However, there are still some further investigations needed to draw final conclusions on the effects of caffeine use in these athletes. Table 14.1 summarises the above-mentioned caffeine studies concerning dosage, timing, type of athletes and performance measures applied in more detail.

14.5.5 Sodium Citrate

The ingestion of sodium citrate indirectly increases bicarbonate concentration and thus the buffering capacity of the blood (Kowalchuk et al. 1989; Lancha Junior et al. 2015). Under these circumstances, sodium citrate has been investigated to enhance short-term, high-intensity exercise performance. However, no performance-enhancing effect in 1500-m wheelchair racing performance was found (Flueck et al. 2014), and 5 out of 9 athletes complained about gastrointestinal side effects after sodium citrate ingestion. Possibly, potential beneficial effects of the supplementation were masked by side effects.

CASE STUDY: USE OF SODIUM BICARBONATE IN A HAND CYCLIST

BACKGROUND

The athlete was a male with paraplegia and had been competing in hand cycling for 10 years, of which 5 years were at the international level. The athlete had competed in four World Championships, one Paralympic Games and four World Cups over the 10-year period.

GOAL

The athlete competed in time trials (TTs), road races (RRs) and team relays (TRs) when the right combination of athletes was available to do so. The athlete had been steadily improving his performances at the international level over the previous 2 years, improving from 11th place to 6th place and then 2nd- and 3rd-place finishes. He felt that he was doing the maximum that he could training- and equipmentwise and was looking for an extra legal edge to help him take the next step to achieve first-place finishes in international competition. He has no desire to use anything illegal in order to improve his performance. His national coach was also a strong antidoping advocate. In order to achieve this goal (Athlete) needed to be able to achieve and maintain a higher average speed in TTs and RRs and be able to respond to, or launch, attacks in RRs. Being able to achieve and maintain a higher average speed would also be beneficial to his contribution to any TR events.

PAST HISTORY WITH SODIUM BICARBONATE

The athlete had had one previous experience with using bi-carb – a highly inappropriate and very negative one. Without any discussion, let alone agreement about it, the athlete's former coach began giving him bottles of water loaded with bi-carb during a 24 hour race. As there were no other fluids provided despite his requests, the athlete was forced to drink the fluid provided to him. The consequences were disastrous and distressing. After the race the athlete was "shitting water" (liquid diarrhoea) but had to catch a long-haul flight home. Very distressed, he sought help from the airport doctor who gave him something to stop it so that he could make the flight home without incident. Not surprisingly, after that experience, the athlete wasn't keen to try bi-carb again.

POTENTIAL REASONS TO CONSIDER SODIUM BICARBONATE LOADING

The TTs required the athlete to maintain a high steady pace over distances of up to 30 km (although they are generally around 15–20 km); the RRs occur over distances of up to 80 km and may involve a range of different strategies, but frequently involve surging to try and break up a bunch and short, high-intensity attacks. The TRs involve teams of three athletes. Each rider completes 1–2 separate laps of a circuit (the number of laps varies according to the lap distance which, in turn, varies according to the courses available to the organiser). TRs generally involve each athlete in a team completing two separate laps of approximately 3 km each. Occasionally the laps are longer and each athlete only completes one lap. The athlete's current national coach felt that the use of bi-carb could help him to buffer the build-up and effects of lactic acid and enable him to maintain a higher average speed as well as making him more physically capable of sustaining, or responding to, attacks in RRs. Although sodium bicarbonate has been proven beneficial to sport performance over only 1–7 min in able-bodied individuals, the athlete's description of what limited his performance in these events was considered to be more an issue of buffering high-intensity exercise metabolites than a cardiorespiratory limitation.

WHAT INFORMATION WERE YOU GIVEN?

Given the athlete's performance goals, training status and lengthy competition experience, the coach felt that the use of bi-carb might be beneficial, under the direction of a sports dietitian/nutritionist. At a meeting early in the training year between the athlete, coach and nutritionist, the athlete's existing race nutrition plan was discussed and strategies for further improving this were considered.

The athlete's previous experience with, and concerns about, the use of bi-carb were also discussed. The sports dietitian/nutritionist was satisfied that the athlete's existing nutritional approach was appropriate and felt that bi-carb could help enhance his performance. Given his past negative experience and reservations, she provided a fact sheet about the use of bi-carb and suggested a conservative approach to re-introducing bi-carb (i.e. lower-than-normal dose for weight to start with; trying it at training first – indoor trainer session near a bathroom in case of any gastric upset first before trying it at an outdoor training session and then in competition, then gradually increasing the doses if there were no side effects). This information was provided but it was left up to the athlete to consider and decide whether he wanted to try bi-carb again. There was no pressure put on him to do so.

(Coach): "If (Athlete) was going to try bi-carb again, I wanted it to be an informed decision and for him to be comfortable and confident about doing so. I thought the best way for this to happen was to discuss the potential benefits/side effects and strategies with a qualified nutritionist, then leave it up to him to make the decision. I was happy to support him in whatever decision he made."

During an early season racing block, the athlete decided that he would like to start trialling bi-carb. The coach asked the sports nutritionist to recommend a conservative protocol that he could start trialling in the lead-up to the 2012 London Paralympics.

WHAT WAS THE PROCESS

The sports nutritionist recommended the following very cautious progression/protocol.

Bicarb Trialling Protocol

Theoretical dose at 0.3 mg/kg BM = 23 capsules each with 840 mg sodium bicarbonate.

Initially I would suggest starting with a lower dose to determine tolerance. So, can we start with 15 capsules and see how it goes.

Trial 1

Rest day or morning/afternoon off, where you can be at home (or somewhere close by a bathroom) just in case there's side effects.

Have a small meal/snack based on carbohydrate and consume 4 capsules with 150 mL water (this is time 0). Always eat with the first dose. What you eat is up to you – you have to bear in mind the training session 2.5 hr later. It doesn't need to be big – could be a slice of toast, sandwich, fruit. Make it something you know sits well on your stomach during high-intensity exercise.

Every 20 mins thereafter, take another 4 capsules with 150 mL water (the last dose will be 3 capsules). So, the last dose should be 1hr after the first dose.

Track any symptoms you have and also the food and fluid you consumed. Usually you would do this starting 2.5 hr before a race, so track your symptoms for at least 3 hr (roughly every 30 mins).

Trial 2

Assuming Trial 1 went fine (if it doesn't, report to me and let me know what happened as we can see what might be modified), then do the same before a turbo session at home. The session doesn't have to be a really hard one – this trial is really to see how you then feel during exercise with the bicarb on board, again monitoring for any side effects.

Trial 3

Assuming Trial 2 went fine, then repeat the process before a hard/high intensity turbo session, interval or hills session.

You can do this as many times as you want to under different circumstances. If the first trial goes well, then you can increase the dose up to the 23 capsules (do this in 2 steps – so take it up to about 19 capsules first, then up to 23).

For 19 capsules, I would do 4 every 15 mins rather than every 20 mins (4:4:4:4:3) so there's 5 dosing points over the 1-hr period, each with 150 mL water.

For 23 capsules, it would be 5:5:5:4:4 (again, every 15 mins with 150–200 mL water). The first time you get to this dose, make it a turbo session at home just in case there are side effects.

Trial 4

In a race situation, same protocol.

Given our race schedule when we returned home (a relatively short period before the races), the sports nutritionist recommended that we complete Trials 1 and 2, as indicated above, during training in Spain and arranged for bi-carb to be provided.

DECISION

In terms of the progression/protocol, we followed the recommended progression/protocol to the letter in terms of the doses, but the type of training session/environment varied a little. This occurred at the athlete's insistence. The first trial (15 cap protocol; half the normal recommended dose for the athlete's weight) was completed during a light training session in the lead-up to a World Cup event (the athlete took a towel, water, change of clothes just in case). When he experienced no side effects except for a few fizzy burps and "gas" afterwards, he decided he wanted to trial the same dose (15 caps, as indicated in Trial 1) in a race. As the coach, I had some reservations about this, but given the lack of any real side effects during training, the fact that it was a low dose (half the normal recommended dose for the athlete's weight) and the athlete's confidence with the protocol allowed him to go ahead.

OUTCOME

The first race in which the athlete re-introduced bi-carb was a World Cup TT 1 or 2 days after the training trial. The outcome? The athlete broke through for his first win in international competition. The athlete felt it definitely helped him – he observed that "I didn't get the muscle burn that I previously got and was able to keep riding harder." Again, the only side effects were some fizzy burps and a bit of "gas" afterwards. He then decided to use the same protocol for the RR. Not far into the race, he dropped his chain on a bumpy descent and had to stop to fix it. He then had to "time trial" it to try and catch the bunch again and came close to succeeding. He still managed to finish in a high place in this race despite having to work solo for most of it. He again felt that the bi-carb provided him with the extra edge he was looking for and was committed to trialling it further. On returning home, he then trialled the higher doses in the recommended protocol in training before trialling them in competition. He now confidently uses the protocol recommended for his weight in competition.

SUBSEQUENT QUESTION RE USE OF BI-CARB WITH YOUNGER, LESS EXPERIENCED ATHLETES

The coach subsequently asked about when it would be appropriate to start trialling bi-carb (or other legal supplements, such as caffeine) with a couple of younger, less experienced athletes who had competed in one block of international racing. The coach's philosophy is that elements such as bi-carb are an "extra" that should only be added once everything else has been addressed (i.e. once bike set-up is appropriate, pedalling technique has been mastered, the athlete is training at the level appropriate for an international athlete and has competed internationally) but was wondering at what point elements such as bi-carb should be introduced. The sports nutritionist agreed with the "extra" philosophy and suggested that it would be best to have the athletes race for another year so that their pacing strategies without bi-carb or caffeine would be mastered before introducing any other elements into the equation.

(Nutritionist): "I would probably wait a little while longer to trial this with (these athletes) – you need to be sure that they have the ability to pace their race effectively first before you layer in bi-carb or anything else, because it will change how they feel in a race and they need to know how to manage this and not "blow up." If their current pacing strategies are variable, then this only adds to the confusion. So I would probably wait a year of international racing before you

> layered this in (same with caffeine) – let them experience what it's like at international level first and get used to how races can be run.
>
> When you feel they're ready to trial it, we would start as we did with (older, experienced Athlete) with a half dose first (according to body mass) and build as per tolerance.
>
> This was agreed to as a sensible approach by the coach.
>
> **Note:** Sodium bicarbonate loading is not necessarily warranted for all hand cycling events. Care must be taken if using it on consecutive days – repeated dosing within a day, or on consecutive days, may induce greater side effects.

14.6 CONCLUSION

Only a limited number of supplements to date show evidence for direct or indirect ergogenic potential in Paralympic sports. Nevertheless, there is a high prevalence of supplement use in Paralympic sports, despite the fact that the impairment- and sport-specific scientific evidence is lacking in most cases. From a practical point of view, individually tailored solutions and recommendations for supplement use are necessary. Therefore, Paralympic athletes must take into account potential physiological differences and sport-specific circumstances when deciding to take a dietary supplement. They should choose products that are independently tested for banned substances, discussing the use of such products in detail with their coach, sports science and medicine support team. In general, supplements should be used with caution and only after a serious risk-benefit analysis, and food-based solutions found wherever possible.

REFERENCES

Abel, T., Kröner, M., Rojas Vega, S. et al. 2003. Energy expenditure in wheelchair racing and handbiking – A basis for prevention of cardiovascular diseases in those with disabilities. *European Journal of Cardiovascular Prevention and Rehabilitation* 10:371–376.

Abel, T., Platen, P., Rojas Vega, S., Schneider, S. and Strüder, H.K. 2008. Energy expenditure in ball games for wheelchair users. *Spinal Cord* 46:785–790.

Bailey, D.G. and Dresser, G.K. 2004. Interactions between grapefruit juice and cardiovascular drugs. *American Journal of Cardiovascular Drugs* 4:281–297.

Baylis, A., Cameron-Smith, D. and Burke, L.M. 2001. Inadvertent doping through supplement use by athletes: Assessment and management of the risk in Australia. *International Journal of Sport Nutrition and Exercise Metababolism* 11:365–383.

Bhambhani, Y. 2002. Physiology of wheelchair racing in athletes with spinal cord injury. *Sports Medicine* 32:23–51.

Brill, J.B. and Keane, M.W. 1994. Supplementation patterns of competitive male and female bodybuilders. *International Journal of Sport Nutrition* 4:398–412.

Buford, T.W., Kreider, R.B., Stout, J.R. et al. 2007. International Society of Sports Nutrition position stand: Creatine supplementation and exercise. *Journal of the International Society of Sports Nutrition* 30:4–6.

Burke, L. and Cato, L. 2015. Supplements and sports foods. In: *Clinical Sports Nutrition* (5th edn), eds. Burke, L. and Deakin, V. pp. 493–591. Sydney: McGraw-Hill Australia.

Burke, L. and Cox, G. 2010. Pills and potions. In *The Complete Guide to Food for Sports Performance*, p. 178. Sydney: Allen & Unwin.

Burke, L.M. 2017. Practical issues in evidence-based use of performance supplements: Supplement interactions, repeated use and individual responses. *Sports Medicine* 47(s1):79–100.

Clénin, G.E., Cordes, M., Huber, A. et al. 2015. Iron deficiency in sports – Definition, influence on performance and therapy. *Swiss Medical Weekly* 145:w14196.

Corrigan, B. and Kazlauskas, R. 2003. Medication use in athletes selected for doping control at the Sydney Olympics (2000). *Clinical Journal of Sports Medicine* 13:33–40.

de Silva, A., Samarasinghe, Y., Senanayake, D. and Lanerolle, P. 2010. Dietary supplement intake in national-level Sri Lankan athletes. *International Journal of Sport Nutrition and Exercise Metabolism* 20:15–20.

Dietary Supplement Health and Education Act (DHSEA). 1994. https://www.congress.gov/bill/103rd-congress/senate-bill/784/text

Felleiter, P., Haeberli, Y., Schmid, W., Tesini, S. and Perret, C. 2017. Post-traumatic changes in energy expenditure and body composition in patients with acute spinal cord injury. *Journal of Rehabilitation Medicine* 49:579–584.

Flueck, J.L., Lienert, M., Schaufelberger, F., Krebs, J. and Perret, C. 2015. Ergogenic effects of caffeine consumption in a 3 min all-out arm crank test in paraplegic and tetraplegic compared to able-bodied individuals. *International Journal of Sport Nutrition and Exercise Metabolism* 25:584–593.

Flueck, J.L., Mettler, S. and Perret, C. 2014. Influence of caffeine and sodium citrate ingestion on 1500 m exercise performance in elite wheelchair athletes: A pilot study. *International Journal of Sport Nutrition and Exercise Metabolism* 24:296–304.

Flueck, J.L. and Perret, C. 2017. Supplement use in Swiss wheelchair athletes. *Swiss Sports and Exercise Medicine* 65:22–27.

Flueck, J.L., Schlaepfer, M. and Perret, C. 2016. Effect of 12-week vitamin D supplementation on 25[OH]D status in elite athletes with a spinal cord injury. *Nutrients* 8:586.

Fynne, L., Worse, J., Gregersen, T., Schlageter, V., Laurberg, S. and Krogh, K. 2012. Gastric and small intestinal dysfunction in spinal cord injury patients. *Acta Neurologica Scandinavia* 125:123–128.

European Parliament and the Council of The European Union. 2002. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0046

Geyer, H., Parr, M.K., Koehler, K., Mareck, U., Schanzer, W. and Thevis, M. 2008. Nutritional supplements cross-contaminated and faked with doping substances. *Journal of Mass Spectrometry* 43:892–902.

Geyer, H., Parr, M.K., Mareck, U., Reinhart, U., Schrader, Y. and Schanzer, W. 2004. Analysis of non-hormonal nutritional supplements for anabolic-androgenic steroids – Results of an international study. *International Journal of Sports Medicine* 25:124–129.

Graham-Paulson, T.S., Paulson, T.A., Perret, C., Tolfrey, K., Cordery, P. and Goosey-Tolfrey, V.L. 2017. Spinal cord injury level influences acute plasma caffeine responses. *Medicine and Science in Sports and Exercise* 49:363–370.

Graham-Paulson, T.S., Perret, C. and Goosey-Tolfrey, V.L. 2016a. Improvements in cycling but not handcycling 10 km time trial performance in habitual caffeine users. *Nutrients* 8:393.

Graham-Paulson, T.S., Perret, C. and Goosey-Tolfrey, V.L. 2018. Case study: Dose response of caffeine on 20 km handcyling time trial performance in a Para-triathlete. *International Journal of Sport Nutrition and Exercise Metabolism* 28:274–278.

Graham-Paulson, T.S., Perret, C., Smith, B., Crosland, J. and Goosey-Tolfrey, V.L. 2015. Nutritional supplement habits of athletes with an impairment and their sources of information. *International Journal of Sport Nutrition and Exercise Metabolism* 25:387–395.

Graham-Paulson, T.S., Perret, C., Watson, P. and Goosey-Tolfrey, V.L. 2016b. Improvement of sprint performance in wheelchair sportsmen with caffeine supplementation. *International Journal of Sports and Physiological Performance* 11:214–220.

Harris, R.C., Soderlund, K. and Hultman, E. 1992. Elevation of creatine in resting and exercised muscle of normal subjects by creatine supplementation. *Clinical Science* 83:367–374.

Hobson, R.M., Saunders, B., Ball, G., Harris, R.C. and Sale, C. 2012. Effects of β-alanine supplementation on exercise performance: A meta-analysis. *Amino Acids* 43:25–37.

Jacobs, P.L., Mahoney, E.T., Cohn, K.A., Sherdassy, L.F. and Green, B.A. 2002. Oral creatine supplementation enhances upper extremity work capacity in persons with cervical-level spinal cord injury. *Archives of Physical Medicine and Rehabilitation* 83:19–23.

Judkins, C.M.G., Teale, P. and Hall, D.J. 2010. The role of banned substance residue analysis in the control of dietary supplement contamination. *Drug Testing and Analysis* 2:417–420.

Kowalchuk, J.M., Maltais, S.A., Yamaji, K. and Hughson, R.L. 1989. The effect of citrate loading on exercise performance, acid-base balance and metabolism. *European Journal of Applied Physiology and Occupational Physiology* 58:858–864.

Krogh, K., Mosdal, C. and Laurberg, S. 2000. Gastrointestinal and segmental colonic transit times in patients with acute and chronic spinal cord lesions. *Spinal Cord* 38:615–621.

Lancha Junior, A.H., Painelli Vde, S., Saunders, B. and Artioli, G.G. 2015. Nutritional strategies to modulate intracellular and extracellular buffering capacity during high-intensity exercise. *Sports Medicine* 45(Suppl. 10):S71–S81.

Lun, V., Erdman, K.A. and Reimer, R.A. 2009. Evaluation of nutritional intake in Canadian high-performance athletes. *Clinical Journal of Sport Medicine* 19:405–411.

Madden, R.F., Shearer, J., Legg, D. and Parnell, J.A. 2018. Evaluation of dietary supplement use in wheelchair rugby athletes. *Nutrients* 10:1958.

Maughan, R.J., Burke, L.M., Dvorak, J. et al. 2018. IOC consensus statement: Dietary supplements and the high-performance athlete. *British Journal of Sports Medicine* 52:439–455.

Maughan, R.J., Depiesse, F. and Geyer, H. 2007. The use of dietary supplements by athletes. *Journal of Sports Science* 25:S103–S113.

Melhus, H., Michaelsson, K., Kindmark, A. et al. 1998. Excessive dietary intake of vitamin A is associated with reduced bone mineral density and increased risk for hip fracture. *Annals of Internal Medicine* 129:770–778.

Miller, E.R. III, Pastor-Barriuso, R., Dalal, D., Riemersma, R.A., Appel, L.J. and Guallar, E. 2005. Meta-analysis: High-dosage vitamin E supplementation may increase all-cause mortality. *Annals of Internal Medicine* 142:37–46.

Navarro, V.J., Khan, I., Björnsson, E., Seeff, L.B., Serrano, J. and Hoofnagle, J.H. 2017. Liver injury from herbal and dietary supplements. *Hepatology* 65:363–373.

Perret, C. and Flueck, J.L. 2016. Supplementation and performance in spinal cord-injured elite athletes: A systematic review. *Deutsche Zeitschrift für Sportmedizin* 67:209–213.

Perret, C., Mueller, G. and Knecht, H. 2006. Influence of creatine supplementation on 800 m wheelchair performance: A pilot study. *Spinal Cord* 44:275–279.

Perret, C. and Stoffel-Kurt, N. 2011. Comparison of nutritional intake between individuals with acute and chronic spinal cord injury. *Journal of Spinal Cord Medicine* 34:569–575.

Pilz, S., März, W., Cashman, K.D. et al. 2018. Rationale and plan for vitamin D food fortification: A review and guidance paper. *Frontiers in Endocrinology* 9:373.

Pritchett, K., Pritchett, R., Ogan, D., Bishop, P., Broad, E. and LaCroix, M. 2016. 25(OH)D status of elite athletes with spinal cord injury relative to lifestyle factors. *Nutrients* 8:374.

Pritchett, K., Pritchett, R.C., Stark, L., Broad, E. and LaCroix, M. 2019. Effect of vitamin D supplementation on 25(OH)D status in elite athletes with spinal cord injury. *International Journal of Sport Nutrition and Exercise Metabolism* 29:18–23.

Ristow, M., Zarse, K., Oberbach, A. et al. 2009. Antioxidants prevent health-promoting effects of physical exercise in humans. *Proceedings of the National Academy of Science USA* 106:8665–8670.

Ronis, M.J.J., Pedersen, K.B. and Watt, J. 2018. Adverse effects of nutriceuticals and dietary supplements. *Annual Review of Pharmacology and Toxicology* 58:583–601.

Scaramella, J., Kirihennedige, N. and Broad, E. 2018. Key nutritional strategies to optimize performance in Para athletes. *Physical Medicine and Rehabilitation Clinics of North America* 29:283–298.

Schantz, P., Sjoberg, B., Widebeck, A.M. and Ekblom, B. 1997. Skeletal muscle of trained and untrained paraplegics and tetraplegics. *Acta Physiologica Scandinavia* 161:31–39.

Shekelle, P.G., Hardy, M.L., Morton, S.C. et al. 2003. Efficacy and safety of ephedra and ephedrine for weight loss and athletic performance: A meta-analysis. *The Journal of the American Medical Association* 289:1537–1545.

Siegler, J.C., Marshall, P.W.M., Bishop, D., Shaw, G. and Green, S. 2016. Mechanistic insights into the efficacy of sodium bicarbonate supplementation to improve athletic performance. *Sports Medicine – Open* 2:41.

Slater, G., Tan, B. and The, K.C. 2003. Dietary supplementation practices of Singaporean athletes. *International Journal of Sport Nutrition and Exercise Metabolism* 13:320–332.

Spendiff, O. and Campbell, I.G. 2005. Influence of pre-exercise glucose ingestion of two concentrations on paraplegic athletes. *Journal of Sports Science* 23:21–30.

Spriet, L.L. 2014. Exercise and sport performance with low doses of caffeine. *Sports Medicine* 44(Suppl. 2):S175–184.

Spungen, A.M., Wang, J., Pierson, R.N. Jr. and Baumann, W.A. 2000. Soft tissue body composition differences in monozygotic twins discordant for spinal cord injury. *Journal of Applied Physiology* 88:1310–1315.

Suzic Lazic, J., Dikic, N., Radivojevic, N. et al. 2011. Dietary supplements and medications in elite sport–polypharmacy or real need? *Scandinavian Journal of Medicine and Science in Sports* 21:260–267.

Thomas, A., Kohler, M., Mester, J. et al. 2010. Identification of the growth-hormone-releasing peptide-2 (GHRP-2) in a nutritional supplement. *Drug Testing and Analysis* 2:144–148.

Tian, H.H., Ong, W.S. and Tan, C.L. 2009. Nutritional supplement use among university athletes in Singapore. *Singapore Medical Journal* 50:165–172.

Tscholl, P., Alonso, J.M., Dolle, G., Junge, A. and Dvorak, J. 2010. The use of drugs and nutritional supplements in top-level track and field athletes. *American Journal of Sports Medicine* 38:133–140.

Tsitsimpikou, C., Jamurtas, A., Fitch, K., Papalexis, P. and Tsarouhas, K. 2009. Medication use by athletes during the Athens 2004 Paralympic Games. *British Journal of Sports Medicine* 43:1062–1066.

Vandenberghe, K., Gillis, N., Van Leemputte, M., Van Hecke, P., Vanstapel, F. and Hespel, P. 1996. Caffeine counteracts the ergogenic action of muscle creatine loading. *Journal of Applied Physiology* 80:452–457.

Womack, C.J., Saunders, M.J., Bechtel, M.K. et al. 2012. The influence of a CYP1A2 polymorphism on the ergogenic effects of caffeine. *Journal of the International Society of Sport Nutrition* 9:7.

15 Practical Sports Nutrition
Challenges and Solutions

Siobhan Crawshay

CONTENTS

15.1 INTRODUCTION

Working with an athlete with an impairment will present new challenges for the sports nutritionist. There is a need to understand and take into consideration practical issues that may arise for the athlete or team, and it is important to be able to think beyond the way one would when dealing with issues in an able-bodied setting.

A good understanding of specific impairment categories is paramount when working with these athletes. This will allow the sports nutritionist to understand the physiological needs and practical factors that should be considered when making recommendations to the athlete. It also provides the knowledge needed to be able to tailor the nutrition consultation better (i.e. certain questions may be triggered by knowing the type of issues athletes may face as a result of their particular impairment). Ultimately, this can lead to a more holistic and satisfactory service for the athlete. It is also important for the health professional to understand and consider the lifestyle practicalities of someone with a specific impairment. An effective sports nutritionist will be able to convey important and relevant nutrition messages to the athlete in a practical and meaningful manner.

Most athletes will already have their home environment set up for their needs and will have ways of completing their daily activities that suit their specific requirements. The athletes are often remarkably adaptable, and are ultimately the most knowledgeable about their own personal needs. For example, it is not uncommon for athletes who use a wheelchair to use escalators, or even to wheel their chairs down a set of stairs, rather than use an elevator when elevators are slow or busy. The athlete therefore provides the best resource and learning opportunity for the service provider, and listening to the specific needs and practical issues that may arise in their daily environment is a key skill.

With the home environment being well set up to suit the athlete, the job of the sports nutritionist is to consider the daily training environment or the environment in which the competition is being held and ensure that the athlete is able to simulate their home environment as closely as possible. Specifically, food access, meal times and locations, whether shopping or self-catering for food is required, buffet setup and travel time to training and competition venues need to be considered in addition to regular sports nutrition principles.

Some athlete groups have been coupled together below in order to discuss common practical issues. However, just as we cannot make generalisations about a team of able-bodied footballers all having similar nutrition requirements, we cannot assume that two athletes who happen to be classed in the same impairment group share the same practical issues or have the same nutritional requirements.

15.2 COMMON PRACTICAL ISSUES WHEN TRAVELLING

Travel times for athletes with an impairment can often be longer than anticipated. Usually, more equipment needs to be carried (e.g. wheelchairs, competition-specific equipment), and wheelchair athletes are often the first to board flights and the last to disembark.

When planning flight travel, consider whether it is best to travel as a whole group of athletes or whether it may be better to split the team into two or more groups. Splitting the team can be a practical way to travel, especially when travelling with wheelchair sports, as it reduces the logistics required by flight and team staff to ensure all chairs and equipment have been loaded on and off. Wheelchair athletes may also require assistance during the flight, so fewer athletes in each group will make travel more manageable.

The location of meals during a training camp or competition needs to be considered. Ideally, this should be close to where the athletes are sleeping or to the training venue to limit the distance the athletes need to travel for meals. Amputees, wheelchair athletes and those athletes who expend more energy in ambulation will be at risk of getting tired and suffering overuse injuries if they need to travel some distance to eat their meals. Spending excessive amounts of time travelling to and from meal service will ultimately take away from valuable training or rest/recovery time.

If athletes are self-catering, they may need more time to prepare their meals and may require assistance with purchasing and transporting food to the accommodation. Self-catering may not be practical for all athletes, as cooking equipment and facilities may not be appropriate, especially in confined spaces.

It is a good idea to bring snack foods and fluids for use by the team at training and competition venues. This allows ready access to recovery food immediately after training.

Allowances will need to be made for other activities the athletes may need to do around meal times. For example, it may take athletes a long time to shower and get ready in the mornings (including time needed for a potential bowel management regime); therefore, scheduling an early breakfast may not allow the athlete to get enough sleep and recovery. Similarly, a meal time late in the evening may not suit an athlete with a bowel management routine which lasts for a couple of hours after the evening meal. Ensuring the nutritionist works closely with the team manager will help to ensure the best solution is found for each individual as well as the whole team.

Maintaining hydration can be a problem for many athletes when travelling, especially nonambulant athletes and those who intermittently catheterise. Difficulties in toileting on a flight, train or bus may lead athletes to consciously reduce their fluid intake to avoid bathroom breaks. Dehydration increases the risk of the athlete acquiring a urinary tract infection (UTI), so education around this topic is strongly advised. This may be as simple as suggesting athletes depart for their trip in a better-hydrated state than usual, consume liquid containing electrolytes (powder, tablet or ready-to-drink electrolyte solutions) en route, and reduce the unit volume but increase the frequency of fluid intake, thereby improving fluid retention. Athletes who usually catheterise intermittently may choose to use an indwelling catheter (IDC) for short-term use. In addition to this, it is crucial to emphasise the importance of good hygiene when self-catheterising during travel, as the risk of infection is greater in public toilets.

Urine-specific gravity (USG) is a practical way of monitoring hydration status and is particularly useful on arrival to a camp or competition and when teams are travelling. Urinary refractometers are relatively cheap, robust, lightweight and user friendly, meaning that other staff members travelling with a team can use them. If not travelling, the sports nutrition practitioner should provide clear and practical guidelines for interpreting this data. Having specific hydration protocols for teams on arrival is also a good idea.

Having a general packing checklist for the team can be helpful, but it is ultimately up to the athlete to remember to bring their specific items such as medications and catheters which can be difficult to source when abroad. Medications should be packed into hand luggage in case there is any lost baggage, and it is advised that athletes bring enough medications for additional days to cover for any travel delays.

Constipation can be a frequent issue, especially for nonambulant athletes after long-haul flights. Therefore, individual discussions around additional fluids and fibre should be undertaken with these athletes, as well as considering their current medication use and bowel routine.

15.3 PRACTICAL CONSIDERATIONS FOR SPECIFIC IMPAIRMENT GROUPS

15.3.1 Spinal Cord Injuries

Ability will vary considerably from those who are completely independent to those who require assistance with tasks of daily living. Most, but not all, spinal cord injury (SCI) athletes will use a wheelchair for ambulation.

Additional time may need to be factored in to the daily programme for showering and dressing, as well as for toileting, depending on the individual's bowel management plan.

The athlete's own kitchen will often be set up to suit the individual so that they can prepare their meals independently. Some higher-level SCI athletes will require some help to prepare meals, so when advising these athletes on specific types of food, it is a good idea to communicate specific suggestions that the athlete can then give to their carer.

Online shopping can be a practical way for the athlete to buy the bulk of their groceries for the week. Assisting the athlete with menu planning over a training week may be a useful process in helping them develop their shopping list.

In terms of hydration, as detailed above, athletes who use wheelchairs often find it inconvenient to go to the bathroom and therefore voluntarily underdrink in situations where bathroom access is uncertain or difficult. This poses issues with dehydration and sports performance, as well as UTIs. Using electrolyte drinks, drinking small amounts across the day and drinking well prior to training and competition all ward against the risk of dehydration. Additionally, when away, ensure the team is aware of accessible toilets at venues, accommodation and at places your team is likely to be visiting. This includes asking the restaurant whether they have accessible toilets to use at meal times.

Due to reduced sweat rates in this population, it is uncommon to see athletes lose significant fluid while training. Instead, fluid is often used as a cooling strategy, and the athletes are at risk of overconsuming fluid during exercise due to the increase in core temperature. Conducting fluid balance testing in their home training environment is important for educating athletes about their specific losses during training. Ideally, this would be done in a few different environmental conditions so that the athletes can gain an appreciation for their range of fluid losses and hence fluid needs.

Regular monitoring of hydration status when travelling is useful for the athlete. The most practical way to monitor hydration status is using a refractometer if available, or simply getting the athletes to monitor their urine colour and urine volume in the morning, and considering frequency of urination throughout the day compared with normal habits. Athletes who have a leg bag should be able to empty a small amount of urine for testing by refractometer. It is important to acknowledge that is it a mixed sample, and where possible, find out when they last emptied the bag. Providing individualised plans to athletes based on their hydration status assists athletes with achieving euhydration. Despite sport drinks being an effective hydration fluid, the energy content of fluids should always be considered when working with this athlete population, due to their likely lower energy expenditure. Low-energy electrolyte drinks during travel are often a better option.

When undertaking anthropometrical assessments, seated or "roll on" scales are encouraged for safer and easier transfer. Large-base platform scales may also be an option if athletes are willing to transfer down to them; however, it is important to check first whether this is possible. Towels may be required to soften the transfer surface, and all surfaces should be carefully checked for sharp edges.

On flights, wheelchair athletes often need to board airplanes first, and are usually the last to disembark, meaning that travel time can be considerably longer. Aisle seating should be requested for these athletes, enabling them to move to the toilet more easily. In addition, an aisle seat allows staff to access these athletes easily if they need to be moved or assisted with pressure lifts on the flight (see below). Alternatively, allowing a staff member to occupy an aisle seat next to an athlete can ensure easy access to the bathroom if the athlete uses a catheter bag or bottle that needs to be emptied. Athletes may also carry a disposable bottle for discreetly toileting at their seat.

Pressure areas and skin injuries in this population are common, particularly after long-haul flights, as a result of the increased number of transfers they are undertaking with equipment that is not their own, or where there are not appropriate pressure relief measures in place. Ensure there is a plan made between the athlete and team physical therapist, and ensure the athlete has asked a staff member to assist with any movement or pressure lifts that need to be completed.

In team settings, it is not usually practical to have the athletes self-cater for all meals. If self-catering is preferred, one option is to organise for breakfast and snack foods to be available in their rooms, then eat as a group for lunch and/or dinner at the hotel or a restaurant. This saves time and effort, and also eliminates any potential risk of an accident when preparing food in an environment not set up for the specific needs of the group.

For buffet eating at hotels, ideally, the buffet tables will be at a height that makes the food accessible for wheelchair athletes (this will be considerably lower than the standard buffet servery).

Finally, when working with SCI athletes, it is crucial to ensure utensils and serving equipment are suitable: they should be lightweight and not require a lot of hand rotation. If the nutritionist can assist with planning meal options, those with small protein pieces (such as casseroles or a stir-fry) will often be more suitable than large meat pieces that require chopping, and avoiding fish and meat with bones is advised.

15.3.2 Cerebral Palsy/Acquired Brain Injury

Cerebral palsy (CP) refers to a range of impairments and affects people in different ways (as outlined in Chapter 7). Some athletes with CP are nonambulant or require significant assistance to walk, and so face some similar challenges to SCI athletes, whereas others have minor physical effects and live completely independently.

Communication boards and various forms of technology provide a way of communicating with those who may find it otherwise difficult. Some athletes with CP have speech difficulties, so having them carry clear written instructions can be useful when out at meals or travelling.

Some athletes with CP find feeding tiring, so when planning mealtimes, it is important to allow for small, frequent snacks to be consumed. Furthermore, ensuring the snacks are nutrient-dense will help the athlete to achieve their nutritional requirements out of these snacks across the day.

As discussed in Chapter 7, some athletes with CP have a higher metabolic demand, due to high energy cost of gait and activities of daily living (ADLs). This means that weight gain and muscle hypertrophy can be a challenge. The dietitian needs to work closely with the coach and strength and conditioning coach to understand the best timing for additional meals, snacks and supplements around training.

The practicalities of athletes with CP eating while travelling need to be considered. Athletes who usually cope adequately with self-feeding at home may need some assistance in the confined space of an airplane seat. In addition, athletes with a high degree of muscle spasticity may require assistance with transfers and pressure relief.

Some athletes may have a limited chewing reflex, resulting in them requiring soft foods and/or thickened fluids, and some athletes may even feed using a percutaneous endoscopic gastrostomy (PEG). It is important that these requirements be communicated prior to travelling, including clear instructions for PEG feeding, so that suitable foods and fluids can be organised.

It may be practical for the athlete to travel with items such as weighted utensils, plates with lips and nonslip placemats to assist with feeding athletes with CP.

As is the case with all individuals travelling, dehydration is always an important consideration.

15.3.3 Amputees

"Amputees" refers to those who have a partial or total amputation of at least one limb; therefore, the range of athletes and their abilities varies dramatically (as outlined in Chapter 8).

Those athletes who are nonambulant (e.g. bilateral leg amputees who do not use prostheses) will face similar practical challenges to those of SCI athletes described earlier. However, if the amputee has a fully functional upper body, their ability to prepare and manage food is better than that of a quadriplegic. Working from a chair in the kitchen may require a specific kitchen setup, including lower bench tops, easy-to-access equipment and appliances that can be easily reached.

Amputees, particularly bilateral leg amputees who walk with prostheses, can tire more quickly when made to stand and walk for prolonged periods. Cooking and shopping should therefore be organised to be as short in duration as possible. Online shopping with home delivery may be a useful option.

Arm amputees can find chopping and preparing food more time consuming, and these athletes will often have specific equipment that makes food preparation easier. Heavy pots and saucepans can also pose problems for arm amputees, so they may cook meals that can be prepared across a few smaller dishes, or may require ideas related to this.

15.3.4 Vision Impairment

Athletes who are vision impaired (VI) often use various technologies and strategies to allow them to live independently with the help of established routines, as outlined in Chapter 10. Travelling can pose some challenges due to the change in their environment, and it will mean the athlete may require additional support while orienting themselves to these changed circumstances. The impact of these changes when travelling should not be underestimated.

When working with a team of athletes, it is important to identify the varying degrees of VI in the group, as this will guide you in the type of considerations that need to be made, as their needs can be very different.

When creating resources for athletes with VI, providing them in electronic format is often the most appropriate. This allows the athlete to enlarge the font or convert it to an audio format as required. All new touch-screen technologies have adaptive software which translates written information into speech.

Some VI athletes are not able to drive and so need to rely on public transport to travel to and from training sessions. Therefore, providing portable recovery snack options is useful due to these extended travel times.

In the home environment, the sports nutrition practitioner should provide very specific advice regarding brand names of foods and the types of packing the food comes in. The bright lights and various colours in a supermarket make it very challenging for athletes with VI, as does the fine print on food packages, making it difficult to compare brands when looking for specific nutrient compositions. If a VI athlete is shopping with assistance, giving detailed advice allows them to give specific instructions to their carer.

When providing guidance about meal options while travelling, giving specific, detailed directions to cafes, restaurants and supermarkets is useful (e.g. "turn left out of the hotel, walk 200 m up the road, and a main supermarket will be on your left side"), as well as indicating what type of foods they can find at said food outlets. Providing a link to the restaurant menu where available helps the athlete to be well prepared.

Vision-impaired athletes may require some assistance from staff with food preparation while travelling. It can be useful for them to pack foods into specific containers they normally use at home so that they can identify things more easily in transit. In addition, having protein containers labelled with large fonts or preparing protein powders into ready-made portions can be of great help to these athletes.

Buffet meal settings are not easy environments for athletes with VI to dine in; however, when travelling with a team, it is quite common for this to be the type of meal service used by venues and hotels. Foods can be difficult to distinguish in bain-maries; the lighting is often not ideal; and the labels (if present at all) are small, meaning that athletes with VI cannot read them. When providing assistance to athletes with VI in these settings, it is essential that all of the foods available be read out to the athlete in the first instance, rather than simply reading the first few options. This allows the athletes to plan their meal appropriately, rather than just filling their plate with the food in the first bain-marie and missing their preferred or the more appropriate option. It is essential that any allergens be identified and clearly communicated to any athletes with allergies in buffet settings.

If liaising with hotels and restaurants regarding menu choices, it is best to avoid fish and meat with bones, as well as other dishes that require "picking."

Some VI athletes use their hands a lot when eating, so education around the importance of hand hygiene is crucial, especially when travelling in different environments where utensils and food containers are often shared across groups.

At restaurants, athletes may have to rely on other people to read out the menu options (unless the menu can be accessed online prior to the meal). They may require assistance once the meal is presented in explaining the positioning of food on their plate, often using a clock system (for example, the meat is at 3 o'clock, vegetables at 9 o'clock). It is important not to move items on the table whose location the athlete has become familiar with, such as fluids.

Using different utensils, knives and stoves/ovens all pose potential risks to the athlete, meaning that self-catering when travelling is rarely a viable option for athletes with VI.

There are several international apps that individuals with VI can use to assist them with many day-to-day needs, for example, "be my eyes" (https://www.bemyeyes.com/) and AIRA (https://aira.io/). These apps can be useful in the kitchen to determine whether food has been cooked adequately, in supermarkets, when looking for locations and for numerous other support services.

15.3.5 Intellectual Impairment

Athletes with an intellectual impairment will vary significantly in how they cope with travel. For some athletes, careful planning with carers may be needed to ensure that the appropriate food and drinks are carried for a journey.

When working with the athletes to plan food intake in the home environment and when travelling, it may be appropriate to create individualised resources for these athletes. Some athletes may prefer written stepwise suggestions, whereas others may work better with picture-based resources.

Some athletes with an intellectual impairment may cope with their daily life by following a strict routine. While trying to maintain this pattern to a degree whilst travelling might be useful, it may not be totally possible and, as a result, eating habits can be severely disrupted. Replacing meals with snacks may not always work well, and having to eat unfamiliar foods can cause problems. These issues will take careful planning, and where possible, the athlete should bring some snack foods that they know they enjoy, in case the destination does not cater well to their preferences. It is important to monitor such individuals to assess how their food and fluid intake has been affected and aim to correct any problems if possible – even if it can only be successfully done after the journey.

Athletes with an intellectual impairment may need more encouragement compared with other athletes to choose appropriate food and fluids for their sports performance. Educating carers, family and friends can be useful to enable them to provide appropriate encouragement to reinforce your advice. Guiding the athletes in the right direction but having them make some of their own decisions is an effective way to educate.

15.4 GASTROINTESTINAL ISSUES SPECIFIC TO PARA ATHLETES

There are some gastrointestinal (GI) tract issues that can be specific to those with impairments, and therefore GI function should be considered when consulting with athletes. Some examples include:

- Athletes who use a wheelchair for competition where they are leaning forward can find it difficult to ingest large amounts of food, fluid or specific types of food. Small volumes of energy-dense foods or fluids can often be a suitable precompetition choice.
- Athletes who have been injured in the line of duty or through motor vehicle accidents may have had surgery to their gastrointestinal tract. This may cause long-term GI issues that need to be managed.
- Athletes with higher-level spinal cord injuries, and some with neurological impairments, have slower GI motility than normal. This can lead to reduced appetite and the potential to underconsume when training loads are higher. Working with athletes to manage changes to dietary patterns and/or nutrient density of foods and fluids according to varying training loads is important.
- Being cautious with any dietary changes in an athlete with spinal cord injuries is useful, especially if dietary fibre, probiotics, iron supplements or any foods with potential laxative effects (such as tart cherry juice) are involved. The side effects of these changes can be more pronounced in these athletes and can result in major disruptions to bowel routines. Ensure changes are made more conservatively initially and in their home environment first.

15.5 PRACTICAL GUIDANCE IN THE KITCHEN

With our fast-paced and busy lifestyles, convenience and preprepared foods are now easy to find in supermarkets. However, as with any new food, it is hard for athletes to navigate the marketing hype and understand which foods are in fact good to include in a healthy diet. Some of these foods can be very useful for athletes with impairments, reducing time and effort needed to prepare meals at home. Below is a list of some foods that may be worthwhile incorporating into an athlete's meal plan.

15.5.1 Fruit and Vegetables

- Frozen vegetables can be steamed, microwaved, roasted or stir-fried with little to no preparation. A great addition to smoothies and juices.
- Frozen or canned fruit (in 100% juice) can be added to cereals, smoothies and juices and in baking.
- Precut fruit and vegetables in the fresh section at the supermarket or local green grocer are often packaged in with other vegetables to make one meal (e.g. stir-fry vegetables or soup mix), reducing wastage.
- Using a blender to chop/slice vegetables is a good way to include more vegetables into dishes such as bolognaise and casseroles, as well as having presliced vegetables ready for salads and sandwiches.
- Dried fruits are a good addition to many salads and hot meals (e.g. tajines) and make a great snack when paired with nuts. There are also several premade trail mix packs available.

Note: Fruits and vegetables are frozen/canned at their peak nutritional value, and the processing only minimally affects this.

15.5.2 Dairy

- Cheese slices and grated cheese provide good alternatives to blocks of cheddar.
- Yoghurts in snack-sized tubs are often more convenient than buying large tubs that need to be dispensed. Natural or Greek-style will have more protein and less sugar.
- Ready-to-drink individual milks may be useful post-training snacks, rather than athletes mixing their own.

15.5.3 Breads, Grains and Cereals

- Microwavable packs of rice, quinoa and other grains are all available at supermarkets. These are great additions to meals, are very quick to heat, and also help athletes to control portions if desired.
- Couscous is the simplest grain to cook, requiring only boiling water to be added. It is a very versatile grain which can be added to salads or used as a side dish.
- Oats/oatmeal are very easy to cook, or soak overnight with nuts, seeds and dried fruit to make a bircher muesli. Oats are also a useful addition to smoothies.

TABLE 15.1
Useful Kitchen Equipment

Equipment/Item	Specific Purpose
Knife with L-shaped handle (e.g. Ulu knife)	Cutting using a single hand.
Chef's knife (8–10″ long)	Used to prep most foods, with length providing versatility and efficiency.
Paring knife	Used for slicing and mincing smaller foods. Avoid with hard foods.
Ceramic knives	When sharp, don't require a perfect angle for cutting. Good option for high countertops.
Cutting boards (large enough to sit on lap)	Hard plastic or sturdy wood with nonslip bottom.
Handheld chopper or large blender	Useful for chopping vegetables, fruit and nuts without use of knife.
Mixing bowls	Choose a set with different sizes and nonslip bottoms. Lids are useful if preparing foods in bulk.
Utensils (range)	• Lightweight handles often easier to manage for some athletes. • Rectangular metal spatula doubles as a serving utensil and slicer • Silicone spatula – easy to scrape side of bowls and is heat resistant.
Handheld blender or bench-top blender	Good for mixing eggs, smoothies, making batters/ sauces etc.
Electric can opener (e.g. "one touch")	Avoid needing to use force to open cans.
Grip jar and bottle opener *or* "one-touch" bottle opener	Assist in opening jars/bottles.
Oven rack puller (wooden stick with hook on end) and long oven mitts with grip	Provides additional safety with use of oven.
Palm peeler and finger guard for chopping with knife	Useful for VI athletes – safety.
Range of pots and pans	Choose multiple sizes that have lids with circular holder to place thumb through for easy pick-up and pans with long handles for easy oven removal.
Baking dishes	Choose with lids, so that they are useful for storing and recooking bulk meals.
Food storage containers	Good for preparing in bulk and freezing individual meals. Choose lightweight plastic (not glass) if hand or arm strength compromised.
Slow cooker	Generally used for meals that require little stirring and you can cook in bulk. If carer assists in morning, long cooking time means meal can be prepared with help.
Rice cooker	Safe, efficient way to prepare rice and other grains (and meats in steamer section if present). Can put rice cooker on bench top that is at suitable height for athlete.

Note: List adapted from U.S. Paralympics Sports Nutrition.

15.5.4 Meats and Meat Alternatives

- Meats can often be purchased precut (e.g. stir-fry chicken or beef strips), or you can ask your butcher to cut meats into the pieces required.
- Buy and freeze individual portions of meat or fish from your butcher or supermarket (or purchase prefrozen pieces) that require little preparation (e.g. salmon fillet can be put into the oven and baked, adding only salt and pepper or spices).
- Canned fish and canned legumes (e.g. chickpeas, beans and lentils) are great sources of protein and fibre, and can simply be drained and added to salads, or stirred through sauces or casseroles.

15.5.5 Kitchen Equipment

There are several kitchen items that can assist athletes with impairments to prepare and cook in a more efficient and safe way. Table 15.1 presents a general list of equipment that may be useful for specific athletes.

General tips:

- Choose nonslip rubber handles for knives, saucepans, etc.
- Sharpen knives regularly to prevent cuts from using blunt knives.
- Always have two chopping boards – one for meats and one for vegetables/fruit.
- Always keep a good variety of spices and herbs handy in the pantry to add instant flavour to meals (e.g. Italian herbs, Mexican spices, cinnamon, chilli, lemon pepper, etc.).

15.6 CONCLUSION

In conclusion, the sports nutritionist needs to consider the daily training and living environment of their athletes. They should try to become as involved as possible in the planning of travel, training camps and competition logistics in order to allow consideration of all areas that can impact the appropriate feeding and nutrition provision to athletes with an impairment. Taking any opportunities to travel with a team or spending time with them in their daily training environment is beneficial. Remember, when working with athletes with an impairment, they are the expert on their own specific needs. Therefore, spend time talking with them to understand their needs better and provide a more valuable nutrition service.

15.7 RESOURCES FOR PRACTITIONERS

- International Paralympic Committee (IPC) – www.paralympic.org
- National Paralympic Committees – many of whom have good resources online
- Professionals in Nutrition for Exercise and Sport (PINES) – now have a Paralympic-specific Facebook page open to members

16 Summary and Future Directions

Elizabeth Broad

CONTENTS

16.1 KEY MESSAGES

Athletes with an impairment are very different even within a specific class. With limited specific scientific information available, some practitioners and coaches may feel "out of their depth" when working with these athletes. Rather than seeing that as a negative, embrace the challenge and be willing to explore. A good grounding in the principles of sports nutrition and in exercise physiology will enable a practitioner to use intuition and experience to support an athlete with an impairment, whether it be someone who is just starting out or an experienced athlete looking to reach the pinnacle of their career. Effective sports nutrition advice that is focussed on performance will help each athlete achieve their own personal goals.

16.2 IMPLICATIONS FOR SPORTS DIETITIANS/NUTRITIONISTS

- Interviews with athletes with an impairment will require more detail than those undertaken with able-bodied athletes. Take the time to understand their impairment, their sport and any clinical issues they may experience.
- Spend time observing the athletes in both training and competition to understand what their sport involves and how it may differ from able-bodied sports/athletes, as well as how their impairment might alter your expectation of energy and nutrient requirements.
- Talk to the athletes' coach(es) about their observations regarding their athletes, such as their energy levels for training, speed of recovery, functional limitations, mood and attention states and general health.
- Involve carers and family where relevant in education and finding practical solutions to issues which require addressing.
- Collate data over time and network with colleagues to develop sufficient pools of information that can be published or used as benchmarks.

- Be prepared to refer on to or consult with other nutrition experts, particularly where clinical issues require management.
- Become involved in planning for trips/travel for training and/or competition. The practical considerations required may sometimes seem challenging; however, finding solutions will help the athletes deliver their best performances.
- Try new or different ways of providing nutrition advice, and be flexible with your nutrition education processes.
- Avoid assumptions. Athletes with an impairment can be highly adaptable.

16.3 IMPLICATIONS FOR ATHLETES AND COACHES

- Actively encourage any opportunity for a sports nutrition professional to discuss with you your training methods and your observations of your athletes and, most importantly, to observe athletes in training and in competition.
- When it does not interrupt training or competition, provide opportunities for individuals such as physiologists and nutritionists to collect data on you/your athletes, as this may help provide a more targeted and specific nutrition support plan.
- Be aware that some things may require some trial and error to get the strategy right. Open communication from all parties will be necessary in order to make this effective for the individual.

COMMENTARY BOX 16.1

ATHLETE'S INSIGHT:

> Ultimately, if you want to reach the pinnacle of your sport you need to take advantage of every resource out there and the nutrition piece is huge. Getting this right not only means your athletic experience will be out of this world, but also your postathletics health will benefit.

Lex Gillette, 4 × Paralympic silver medallist, 3 × world champion and current world record holder (6.73 m) in long jump (F11).

16.4 FUTURE RESEARCH DIRECTIONS

Throughout this book, numerous deficits in our knowledge have been highlighted, which provides a range of options for future research. Due to the relatively small numbers of individuals with "similar" impairments in one location or one country, there is potential value in collaborative research projects within, or between, nations. Some of this research is of a practical nature and could therefore be undertaken by collating relevant data over an extended period of time, while other projects most likely will require equipment and expertise that can only be found at universities or specific research institutions. Practitioners are encouraged to develop a network of colleagues with whom they could collaborate and communicate regularly.

The following topics are a summary of some of the key areas that could be explored:

- Physiological requirements of a range of different sporting events and activities undertaken by athletes with an impairment.
- Fuel utilisation during exercise in athletes with specific types of impairment, such as cerebral palsy, spinal cord injuries, amputees etc.
- Glycogen storage capacity and utilisation during exercise of athletes with a spinal cord injury.
- Benefits of carbohydrate intake before and during exercise in Para athletes.
- Protein requirements postexercise for athletes with specific types of impairment (particularly spinal cord injury).
- Energy expenditure both at rest and during exercise in athletes with a range of impairments.
- Energy availability in Para athletes and determination of the optimal risk factors to assess and monitor.
- Core temperature changes during exercise in a wide range of impairments.
- Role and effectiveness of cooling strategies across a wide range of impairments.
- Heat acclimation protocols and effectiveness in Para athletes.
- Combined effects of spinal cord injury and exercise on gastric emptying and nutrient absorption.
- Validation, or cross-comparison, of methods of assessing body composition and physique in specific impairment types.
- Long-term monitoring of a variety of anthropometrical measures using various tools to determine the physique traits of elite athletes with an impairment and provide benchmark data and correlations to performance.
- Incidence of vitamin D deficiency in athletes with an impairment and optimal prevention and management strategies.
- Nutritional prophylaxis for urinary tract infections, especially in individuals with neurogenic bladder.
- Role of omega-3 fatty acids in management of neurological symptoms in Para athletes.
- The effectiveness of nutritional supplements and ergogenic aids specifically for athletes with an impairment, including the potential need for modifying protocols to suit specific impairment types.
- Nutritional interventions to restrict the progression of eye diseases in vision impaired athletes.

In summary, simple practical investigations and more complex clinical or laboratory-based studies alike will increase the ability of practitioners to more fully understand and correctly advise athletes with an impairment and their coaches to get more out of their sporting experiences.

Appendix

PARA SPORT FEATURE

Sport:	Archery
Disciplines:	Recurve, compound
Permissable Impairments:	Physical impairments such spinal or nerve injury, limb deficiency/loss, cerebral palsy or similar
Classes:	Standing (ST), wheelchair 1 (W1), wheelchair 2 (W2), both men and women

Brief Description

In individual events, archers shoot 72 arrows (12 “ends” of 6 arrows each) at a target that has 10 scoring circles, the aim being to get as close to the centre as possible (the centre circle being 10 points). Athletes are allowed 4 minutes per “end.” Top-scoring athletes advance to 15-arrow head-to-head matches. There are also team events with three archers per team in a best of 24-arrow format.

Rule Differences to Able-Bodied Sport

- A recurve archer shoots at a 1.22-m diameter target 70 m distance from the shooting line.
- A compound archer shoots at an 80-cm diameter target 50 m distance from the shooting line.
- Adaptive equipment is allowed to assist the athlete in shooting the arrow (e.g. those with upper-limb deficiencies).

Photo

Photograph courtesy of Jacque Scaramella.

Sport:	Badminton
Disciplines:	Men's and women's singles, men's and women's doubles, mixed doubles
Permissable Impairments:	Most physical impairments other than vision, short stature
Classes:	There are six classes – two wheelchair classes, two standing classes for lower-limb impairments, one standing class for upper-limb impairments and one class for short stature

Brief Description

Tokyo 2020 will be the first time para badminton has been included in the Paralympic games program. It is an indoor sport played on a rectangular court where a "shuttle" is hit across a net from one side to another. A match consists of the best of 3 games each of 21 (or up to 30 if less than 2 points separate opponents) points. A point is scored every time there is a serve and goes to the person/team who wins the rally.

Rule Differences to Able-Bodied Sport

The rules followed are the same as for able-bodied badminton with the exception of allowable sports equipment such as prostheses and wheelchairs.

Sport:	Boccia
Disciplines:	Singles, teams, pairs
Permissable Impairments:	Physical impairment that affects the motor skills of the entire body, such as cerebral palsy, acquired brain injury or muscular dystrophy
Classes:	BC1–BC4

Brief Description

An indoor sport played by athletes in wheelchairs, on a flat, smooth surface defined by a box 12.5 × 6 m. Athletes throw, kick or use a ramp device to propel a leather ball as closely as possible to a white ball which serves as a target ("jack"). The ball closest to the jack wins a point, with an additional point for every other ball belonging to that individual/team that is closer to the jack than their opponent's ball is. Six balls are propelled each "end," with four ends for individual and pairs games and six ends for team events.

Rule Differences to Able-Bodied Sport

There is no able-bodied Olympic counterpart sport; however, the rules are similar to lawn bowls. The balls are of a defined weight and size.

Sport:	Cycling
Disciplines:	Men's and women's road and track events. Road events – individual time trial, team time trial and road race Track events – team sprint, tandem sprint, 500 and 1000 m time trial, individual pursuit
Permissable Impairments:	Vision and a wide range of physical impairments
Classes:	Road – hand cycle (five subclasses, H1–H5), tricycle (two subclasses, T1 and T2), tandems (B1–B3) and standing 2-wheel (five subclasses, C1–C5) Track – standing 2-wheel (five subclasses, C1–C5) and tandems (B1–B3)

Brief Description

Cycling is competed on either the road (standard roads which are closed for the competition) or a regular velodrome track. In some instances, athletes will compete in both track and road events within a year.

Rule Differences to Able-Bodied Sport

- A standard bike helmet must be worn for all racing, and each road racing class has a specific helmet colour. Depending on class sizes, road races may combine at least two classes at the start of the race and they may draft off each other during the race; however, the final race placings are according to the individual class. Drafting off riders from a different start group is not allowed.
- Adaptive devices are permitted provided they comply with specific guidelines.

Photo

Sport:	Football five-a-side
Disciplines:	N/A
Permissable Impairments:	Vision impairment
Classes:	B1 (complete vision impairment) for onfield players, B2–B3 or sighted for goalkeeper

Brief Description

Two teams of five players compete against each other to try and kick the ball into the opposition team's goal net.

Rule Differences to Able-Bodied Sport

- Four players on the field plus the goalkeeper.
- Fifty-minute game – 2 × 25 min halves.
- The field measures 40 m long and 20 m wide, and the full length of each side is covered by kickboards to prevent the ball going out of play.
- No offside rule.
- The ball makes a sound as it moves.
- All onfield players must wear a blindfold for fairness.
- Goalkeeper can be partially or fully sighted and can act as a guide during play. There is also a sighted guide placed behind the goal for when players are shooting.
- Spectators must remain silent during play so the players can hear the ball.

Sport: Goalball
Disciplines: Men's and Women's
Permissable Impairments: Vision impairment
Classes: Only one class – all athletes compete with a blindfold on

Brief Description

Goalball is a team sport where three players on each side are on the court at any one time. The game is played in two halves of 12 min duration each with 3 min break at half time. The court is 18 m × 9 m and divided into two halves, and has a goal at each end which extends the full 9 m length of the end line. Players throw a ball along the ground which has a bell in it so that its trajectory can be tracked by sound. A point is awarded for every ball which successfully lands in the opposition's goal. Opponents can lie on the ground to block the ball. Audiences must remain silent through periods of play to ensure athletes can adequately hear the ball and the movements of their own and opposition players.

Rule Differences to Able-Bodied Sport

There is no equivalent able-bodied sport.

Sport:	Judo
Disciplines:	Men's and women's, each subdivided into weight categories At the 2016 Paralympic games' there were seven weight divisions for men (60, 66, 73, 81, 90, 100, 100+ kg), and six for women (48, 52, 57, 63, 70, 70+ kg)
Permissable Impairments:	Vision impairments in both eyes
Classes:	All classes of vision impairment compete together in the same weight division

Brief Description

Judo is a martial art competed over 4 (females) to 5 (males) minutes in a defined ring of 8×8 m. The goal is to score as many points against your opponent by skilful attacks of throws, holds, armlocks and strangles, or to score an "Ippon" by throwing your opponent such that their back is on the mat, immobilising them or forcing a submission.

Rule Differences to Able-Bodied Sport

Judokas commence, and remain throughout the combat, holding on to their opponent's clothing.

Sport: Para Alpine skiing

Disciplines: Speed events (downhill, Super G, each one run only), technical events (slalom, giant slalom, each two runs with combined total) and combined (downhill or super G and slalom, one run of each)

Permissable Impairments: All except intellectual impairments

Classes: Sitting (LW10–12), standing (LW1–9) and VI (B1–3), for both genders

Brief Description

Alpine skiing combines agility and speed. Skiers ski down a hill at the fastest possible speed (often reaching 100 km/h) while negotiating a course that varies in length, use of gates and terrain. All skiers within a class race against each other; however, a times factoring system is applied for each subclass to provide a more even playing field. VI athletes and their guides (who ski ahead of them on the course) communicate via a Bluetooth radio headset.

Rule Differences to Able-Bodied Sport

- Length of race courses are shorter than for able-bodied skiers, but the same course is used for both males and females and for each class.
- A sit ski comprises a bucket (seat), a single ski and a shock absorber, and the skier carries two outriggers which are held in each hand to help stabilise the skier.
- Standing skiers are allowed prostheses according to their impairment. This may include outriggers for a single-leg amputee.

Sport:	Para athletics (track & field)
Disciplines:	Throws – club, shot put, discus, javelin Jumps – high jump, long jump, triple jump Track – 100m through to marathon
Permissable Impairments:	All – although not impairment classes are able to compete in all events
Classes:	T = track, F = field T/F11–13 – vision impairment T/F 20 – intellectual impairment T/F 31–38 (coordination impairments, 31–34 compete in wheelchairs or seated), 40–41 (short stature), 42–47 (limb deficiency without use of prosthesis), 51–54 (wheelchair), 61–64 (limb deficiency competing with prosthesis or leg length difference) – physical impairments

Brief Description

Para athletics involves a large number of events, generally with multiple categories, each having their own event. For example, T11 100 m is a different race from T12 100 m. Due to the sheer number of events, not all of them are selected for competition at the Paralympic games – for instance, a T34 may only have 100 and 800 m available to compete in at the Paralympic games. In 2008, there were 160 medal events in Para athletics – a drop from 234 medal events in 2000 with over 1000 athletes competing. It is not unusual for athletes to compete in multiple distances or to compete in both track and field events within the one competition.

Rule Differences to Able-Bodied Sport

There are some permissible equipment differences for some athletes:

- Tethers are allowed between guides and vision impaired runners, or an acoustic device or sighted "caller" in jumping events for vision impaired.
- Wheelchairs are considered adaptive equipment but must comply with specific dimensions and features.
- Seated throwers have a seated piece of equipment which may include tie downs and a form of leverage.
- Amputees may use prosthetic devices. There is a maximal height allowance for bilateral lower-limb amputees.

Sport:	Para ice hockey (formerly known as sled hockey)
Disciplines:	Only one discipline, can include both males and females on same team
Permissable Impairments:	Lower-limb affected (amputee, spinal cord injury, lower-limb affected CP)
Classes:	Only one class – all athletes compete on a sled

Brief Description

Para ice hockey is played by six athletes per team (including one goalkeeper) being seated on a sled throughout play. The game is played in three 15 minute periods.

Rule Differences to Able-Bodied Sport

- Players may use two sticks with blades in order facilitate stick handling and ambidextrous shooting.
- Double-blade sledges that allow the puck to pass underneath.
- The sledge may be made of aluminium or steel, curved at the front and a minimum of 80 cm in length.
- The sledge has a seating system called a bucket which may have a backrest, but it must not protrude laterally beyond the armpits when the player is seated properly. Straps secure a player's feet, ankles, knees and hips to the sledge.

Photo

Photograph courtesy of Jacque Scaramella.

Sport:	Para Nordic ski
Disciplines:	Cross country and biathlon. Each have various distances (from 2.5 to 20 km) and race formats (generally three primary ones within each discipline at a major event such as Paralympic games)
Permissable Impairments:	All except intellectual impairments
Classes:	Sitting (LW10–12), standing (LW2–9) and VI (B1–3), for both genders

Brief Description

Skiers race on a looped course of a set distance (number of loops varies with the total race distance). In biathlon, each loop is interspersed with a 5-shot shooting period, with penalties applied (either time or an extra ski distance) for each missed shot. All skiers within a class race against each other; however, a times factoring system is applied for each subclass to provide a more even playing field. VI athletes and their guides communicate via a Bluetooth radio headset or voice commands. Men and women may race different distances, and standing/VI athletes may race a different distance to sit skiers in the same event.

Rule Differences to Able-Bodied Sport

- In biathlon, rifles are handed to athletes by a coach/support staff rather than athletes having to carry them with them during the race.
- The biathlon target is 10 m distance from the shooting zone, 20 mm in diameter for sit and standing skiers and 30 mm in diameter for VI athletes.
- Shooting "stance" in biathlon races is always prone, not standing.
- In biathlon, vision impaired athletes use an electronic rifle with acoustic signals that indicate proximity to the target.
- Sit skiers only ski a "classic" course, whereas standing and VI will race both "classic" and "skate" ski formats.
- Vision impaired athletes race with a guide.
- The sit ski involves a "bucket" (the seat) which sits on a frame that has ski bindings on the bottom to attach to a pair of skis. The ski skier is not allowed to raise their buttocks off the seat while skiing.

Photo

Photograph courtesy of Elizabeth Broad.

Sport:	Para powerlifting
Disciplines:	Males and females subdivided into 10 weight classes – from 49 kg to over 107 kg in males, and 41 kg to over 86 kg in females
Permissable Impairments:	Physical impairments of the lower limbs or hips that would inhibit them from competing in able-bodied weight lifting. This includes cerebral palsy, lower-limb deficiencies, short stature, spinal cord injuries and other impairments that meet the first criteria
Classes:	All impairment types compete against each other within a weight category

Brief Description

Each athlete is given three attempts to bench-press the highest possible weight they can. The winner is the athlete who lifts the highest weight in kg (or in the case of a draw, the highest weight per kg body mass). The bar must be lowered to their chest, held motionless at their chest, then pressed up to full arm extension with elbows locked and minimal movement.

Rule Differences to Able-Bodied Sport

- Para powerlifting is a bench press from a prone position only on a bench 2.1 m long and 61 cm wide.
- All lifters must wear a collar weighing 2.5 kg during their lift.

Sport:	Para snowboard
Disciplines:	Snowboard cross, banked slalom and, for 2022 Beijing games, giant slalom
Permissable Impairments:	Male and female leg or arm impairments
Classes:	SB-LL1 (above-knee amputee in one leg or significant deficits in both legs such as significant muscle spasticity or weakness in both legs)
	SB-LL2 (below-knee amputee in one leg or less significant deficits in both legs such as mild spasticity)
	SB-UL (upper-limb impairment)

Brief Description

Snowboard cross: Athletes have three runs down a course that involves a medium-pitched slope and varying terrain. Their best run determines the final order based on ascending time.

Banked slalom: For qualifying, athletes have three runs down the course to post their best time, with only one rider on the course at a time. Finals consist of the top 16 men or 8 women competing head to head (2 riders on the course at a time). Rounds are completed until the final four are nominated. Two riders then compete for the bronze medal, and two compete for the gold medal.

Rule Differences to Able-Bodied Sport

Use of prostheses in lower-limb amputees and appropriate adaptive equipment.

Sport:	Para swimming
Disciplines:	Men's, women's and mixed 4 × 100 medley relay 50–100 m distances for backstroke, butterfly and breaststroke 150–200 m for individual medley 50–400 m distances for freestyle
Permissable Impairments:	All
Classes:	Athletes can be classed as S for freestyle, backstroke and butterfly events; SB for breaststroke and SM for medley events Classes S1–10 are physical impairments (a lower number means a more severe activity limitation than a higher number) Classes S11–13 are vision impairments Class S14 is intellectual impairments

Brief Description

Swimming is a race to be the fastest to finish the set distance in the event.

Rule Differences to Able-Bodied Sport

- The same rules apply as for able-bodied sports in terms of equipment, false starts etc.
- Vision impaired athletes may have a "tapper" at each end of the pool to tap them on the head or shoulder when they're approaching the end of the lane. S11 (the most vision impaired) *must* have a tapper; for the other classes, it is optional.
- All S11 swimmers must wear blacked-out goggles in order to ensure complete fairness across the class.
- Hearing-impaired athletes may have a light to signal the start of a race.
- Some athletes may have in-water starts, holders (to keep them steady on the starting blocks) or specific starting platforms according to their impairment.

Sport:	Rowing
Disciplines:	Men's and women's single sculls (PR1M1x and PR1W1), mixed double sculls (PR2Mix2x) and mixed coxed 4 (PR3Mix4+)
Permissable Impairments:	Vision and physical impairments
Classes:	PR1 – athletes with physical impairments that are limited to the use of arms and shoulders only
	PR2 – athletes with physical impairments that are limited to the use of trunk and arms only
	PR3 – athletes with physical impairments that involve the use of legs, trunks and arms, or vision impairments

Brief Description

Raced over 2000 m, athletes compete in a series of heats, repecharges and finals to determine which boat is fastest.

Rule Differences to Able-Bodied Sport

- Smaller boats (singles) are equipped with buoyancy-device pontoons, providing additional lateral balance.
- Seats in PR1 and PR2 boats are fixed.
- Seats may have postural support or complementary support depending on the impairment type.

Sport:	Shooting Para sport
Disciplines:	Pistol, rifle and trap; males, females and mixed; 10, 25 and 50 m
Permissable Impairments:	All physical impairments
Classes:	SH1 pistol – upper and/or lower-limb impairments. May shoot standing or seated
	SH1 rifle – lower-limb impairments (compete as seated or prone)
	SH2 rifle – athletes with upper-limb impairments which require the use of a shooting stand to support the rifle. May or may not have lower-limb impairment
	SG-S trap – impairment of lower limbs that requires them to shoot from a seated position. No functional limitation to upper limbs
	SG-L trap – lower-limb impairments with good functional balance and trunk control that enables the athlete to shoot in a standing position. No impairment to upper limbs
	SG-U trap – impairment to nonshooting upper limb. Good balance and trunk function and shoot from standing position

Brief Description

Athletes shoot either a pistol or rifle to a target that is a set distance away, scoring points according to how close their shot lands to the centre of the target.

Rule Differences to Able-Bodied Sport

- Five different targets are used depending on the type of gun and distance covered.
- Bullets are 4.5 mm diameter for 10 m events, 5.6 mm diameter for other events.
- Athletes use 0.22-caliber rifles and air guns.

Sport: Sitting volleyball
Disciplines: Men's and women's
Permissable Impairments: Lower-limb physical impairments
Classes: MD – most physically able
D – least physically able

Brief Description

The game is played in a best-of-five set format and the first to reach 25 points (with at least a 2-point lead) wins the set. Two teams of six players project the volleyball over a net from a seated or kneeling position until the opposition either allows the ball to touch the ground or the ball goes out of bounds, at which time the opposition team gets control of the ball. The ball is allowed to be touched up to three times before it must clear the net to the opposition side. Players rotate around the court at the start of each new server (i.e. whenever control of the ball changes to the opposite team).

Rule Differences to Able-Bodied Sport

- Court dimensions are smaller (10 m × 6 m) and net height is lower (1.15 m for men, 1.05 m for women) than in able-bodied volleyball.
- At all times, a player's pelvis must be touching the ground.
- A maximum of one MD player may be on the court for each team at any one time.

Photo

Photograph courtesy of Jacque Scaramella.

Sport:	Table tennis
Disciplines:	Men's and women's individual, doubles and team events
Permissable Impairments:	Physical and intellectual impairments (not vision impairments)
Classes:	TT1–5 are seated players TT6–10 are ambulatory players TT11 are players with intellectual impairment

Brief Description

Matches are competed as a best of five games, each of 11 points.

Rule Differences to Able-Bodied Sport

The rules for Para table tennis are similar to able-bodied with slight modifications to the service rule for wheelchair users.

Sport:	Taekwondo
Disciplines:	Kyorugi (sparring discipline) will be the form competed in at Tokyo 2020, although there are also competitions in poomsae (martial arts form)
Permissable Impairments:	Limb impairments and arm amputees for kyorugi. Neurological impairments, vision impairments and intellectual impairments may compete in poomsae
Classes:	Four classes per gender – K41 through to K44. Within each class there are weight divisions. Males are under 61 kg, under 75 kg and over 75 kg, whereas females are under 49 kg, under 58 kg and over 58 kg K41 – bilateral limb deficiency/amputee with <1/3 of arm remaining K42 – unilateral <1/3 arm or bilateral above elbow limb deficiency/amputee K43 – bilateral through elbow or below limb deficiency/amputee K44 – unilateral through or above wrist or foot/ lower leg deficiency or arm dysfunction (e.g. hemiplegic CP)

Brief Description

Taekwondo will be competed in for the first time at the Paralympic games in Tokyo 2020. It is fought as one single-round, 5-minute fight with coaches allowed one time out. This has recently been changed from a 3 × 2-minute bout competition.

Two points are awarded for a valid foot technique to the trunk protector, 3 points for a valid turning foot technique to the trunk protector, and 4 points for a valid spinning technique to the trunk protector. In addition, one point is awarded for every Gam-jeom (a penalty deduction) given to the opponent.

Rule Differences to Able-Bodied Sport

Head kicks and trunk punches are not legal in Paralympic competition.

Sport: Triathlon

Disciplines: Men's and women's

Permissable Impairments: Physical and vision impairments

Classes: PTWC (two subclasses) for wheelchair-dependent athletes, including those with muscle power, lower-limb deficiency, hypertonia, ataxia or athetosis

PTS2-5 for physical impairments, ranging from most severe (PTS2) to least severe (PTS5)

PTVI (three subclasses) for vision impairments

Brief Description

Para triathlon is competed as a sprint distance event – 750 m swim, 20 km cycle and 5 km run.

Rule Differences to Able-Bodied Sport

- Adaptive equipment is allowed according to impairment type. For example, a tandem bike, standard bike or handcycle may be permitted on the cycle leg and a wheelchair racing chair may be permitted on the run portion. Vision impaired athletes may be tethered to their guide during swim and run portions. Athletes can receive assistance between getting out of the water postswim to the transition zone, and may receive support for transfers between sectors if wheelchair dependent.
- Guides must be of same gender and nationality and must be with the athlete the entire race.

Photo

Photograph courtesy of Jacque Scaramella.

Sport: Wheelchair basketball

Disciplines: Men's and women's

Permissable Impairments: Permanent physical impairment to lower limbs that prevents them from running, jumping and pivoting as an able-bodied player

Classes: Players are assigned a point value between 1 and 4.5 according to their level of physical function

Brief Description

Team sport played over four quarters of 10 minutes each where the goal is to score as many points as possible in the opposing team's basket. All athletes compete using a wheelchair with cambered wheels. The wheelchair is considered part of the body.

Rule Differences to Able-Bodied Sport

- Rules followed are very similar to able-bodied basketball. Five players are allowed on court for each time, but the total "points" can not exceed 14.
- Players in possession of the ball are allowed to push their chair 1–2 times before having to dribble or pass the ball.

Photo

Photograph courtesy of Elizabeth Broad.

Sport: Wheelchair curling

Disciplines: Both men and women compete together in a team of four – two males, two females

Permissable Impairments: Physical impairment in lower half of body, including spinal cord injuries, double-leg amputee, cerebral palsy and multiple sclerosis and require a wheelchair for daily mobility

Classes: There is no specific class. All athletes compete in a wheelchair

Brief Description

Curling is a sport where a stone is slid down a layer of ice towards a target which involves a series of four concentric circles. It is related to bowls and boules. Each team has 8 stones and points are accrued for the number of stones closest to the centre of the target at the completion of each “end.” There are 8–10 “ends” per game.

Rule Differences to Able-Bodied Sport

- There is no “sweeping.”
- It is possible to use an “extender cue” to deliver the stone.

Photo

Photograph courtesy of Jacque Scaramella.

Sport:	Wheelchair fencing
Disciplines:	Foil, epee (men and women) and sabre (men); can be competed as single athletes or a team of three
Permissable Impairments:	Amputations, spinal cord injuries and cerebral palsy
Classes:	Class A = full trunk control and hand movement Class B = limitations in trunk balance and control

Brief Description

Athletes compete in wheelchairs that are fastened to the floor where the inside wheel is covered by metal detachable shields. Athletes use an electronic system to score points by hitting the opposition's body (various sites are allowed according to the type of sword used). In preliminary rounds, fencers fight to 5-point games. In the knockout stage, they fight up to 15 points.

Rule Differences to Able-Bodied Sport

- Legs must be protected by thick clothes or apron.
- Fencers who have significant loss of hand grip or control of the sword may attach the sword to the hand using a bandage or similar wrapping.

Sport:	Wheelchair rugby
Disciplines:	Men and women can compete on the same team
Permissable Impairments:	Physical impairment to all four limbs such as spinal cord injury (quadriplegia) or limb loss of both arms and legs
Classes:	Athletes are assigned a point value ranging from 0.5 to 3.5 based on their functional ability – the higher the points, the more functional ability they have

Brief Description

Wheelchair rugby is an indoor sport played with a volleyball that can be passed in any way other than being kicked. One point (a goal) is awarded when a player crosses a defined section of the opposition's goal line and must occur within 40 seconds of the team receiving possession of the ball. It is played in four quarters of 8 min duration with breaks between quarters, with time outs allowed. There are four players allowed on court per team; however, the total "points" on court per team cannot exceed eight.

Rule Differences to Able-Bodied Sport

- Wheelchair rugby is played on an indoor court the same size as a basketball court.
- The rules are somewhat similar to basketball. The ball must be bounced or passed at least every 10 seconds, and players have limited time to be within sections of the court during play.
- Wheelchair rugby is a full-contact sport. Chairs must be lightweight and easy to manoeuvre yet robust to protect the player. Wheelchair rugby chairs are unique in that they must have spoke protectors and antitip devices, and include bumpers at the front.

Sport:	Wheelchair tennis
Disciplines:	Men's, women's and quad tennis played as singles or doubles
Permissable Impairments:	Physical impairment resulting in permanent substantial or total loss of function in one or both legs. For quad tennis, impairment to at least three of the four limbs
Classes:	Wheelchair and quad

Brief Description

Wheelchair tennis is played as a best of three sets, using the standard rules of tennis.

Rule Differences to Able-Bodied Sport

The main differences between able-bodied tennis and wheelchair tennis are the use of wheelchairs and the two-bounce rule (the ball is allowed to bounce twice before being hit). The first bounce must be within the bounds of the court.

Index

D

G

H

I

N

O

P

T

U

V

W

Z