Arthur Jason De Luigi
Editor

Adaptive Sports Medicine

A Clinical Guide

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Editor
Arthur Jason De Luigi
Professor of Rehabilitation Medicine
Georgetown University School of Medicine
Washington, DC
USA

ISBN 978-3-319-56566-8 ISBN 978-3-319-56568-2 (eBook)
DOI 10.1007/978-3-319-56568-2

Library of Congress Control Number: 2017950495

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

I would like to dedicate this book to my family because if it were not for their love and support, I would not be where I am today. I particularly would like to thank my wife Beata, who has endured my many hours of research and literature review and countless hours on the computer. The time dedicated to this textbook has taken me away from my duties at home, and I have a great deal of work around the house. I would also like to thank my children, Oscar and Cyan, and their efforts to allow me a few quiet hours in the early morning on weekends and the unconditional love they give to me. They always knew that I would be there for them each day when I was done, so we can enjoy family time together. I would like to thank my parents, Shirley and Art, who gave everything they had to get me to college and flourish. I know these last few years have been hard on my dad, since my mom has passed, and he has remained strong. I really wish my mother were here today, because I know how proud she would be and would make sure that everyone knew the work I accomplished. I cannot forget my brother, Corey; grandmothers, Marge and Charlene; and particularly my grandfather, Art. It is my *grandfather's traumatic brain injury that led me into a career in medicine and to pursue a career in helping persons with disabilities. He never gave up his life's dream as an artist despite the brain injury, and because of his drive and perseverance, I knew that I could accomplish anything.*

Arthur Jason De Luigi, DO

Preface

The world of Adaptive Sports Medicine is growing every day, as we grow as a society. In the past, when a person suffered a catastrophic injury, there was a focus in the society and the medical world on what these persons could no longer do. However, as we matured as a society and as a medical community, our eyes were opened to the possibility of what we can offer these persons in terms of fulfillment and opportunity.

It was the early pioneers who worked on sporting competitions for those in wheelchairs who laid the initial path, but it is the many visionaries and caring individuals who have allowed this world to blossom.

The primary reason that I fell in love with the field of Adaptive Sports Medicine was that these opportunities gave hope back to these individuals who were injured. This hope allowed them to see that they could achieve again rather than focus on what they have lost.

It was my childhood experience with my grandfather that set the foundation of a pathway that I had not even envisioned I would travel. When I was 3, my grandfather, who painted bridges for a living, suffered a major traumatic accident. One day at work, the scaffolding broke, and he plummeted from the bridge. He was rescued and flown via helicopter to a major trauma center. He survived the fall but suffered a major traumatic brain injury and lost his hearing. He recovered after a long hospitalization and prolonged rehabilitation course, but he would never be able to work again. Instead of focusing on what he could no longer do, he instead developed a passion for art. He began painting as part of his rehab process and fell in love with it. Over time, his skills grew and his work flourished. He began to expand his artistic endeavors to include wood carving and marble and bronze sculpturing. Every time we would visit him, you would see the passion and the energy in his work and the pride he had in showing everyone what he was able to do instead of what he was no longer able to do.

I immediately saw this same type of passion in the Wounded Warriors at Walter Reed National Military Medical Center during my internship and residency. Despite the major traumas these individuals sustained while protecting our freedom, they continued to fight to get back to the life they knew. Many returned to active duty and redeployed despite having lost limbs fighting in the same conflict, whereas others found new goals in the arena of Adaptive Sports Medicine.

I have had the pleasure to work alongside these great servicemen and women in uniform on the battlefield as well as in the rehabilitation center, and it is their passion, coupled with the passionate medical and rehabilitation staff at Walter Reed, that has made these lives whole again.

I knew that this was a field that I wanted to devote my time and efforts to, and I wanted to help make a difference in these people's lives. I quickly realized that what we were doing could not be found in any text, and it took extensive research to find any of this information in the medical literature.

My goal with this text is to create a source of information on Adaptive Sports Medicine that is beneficial to the medical community who are involved in the care of those with disabilities interested in sports, but also those with injuries who may not know what some of the sports options are available to them.

The text begins with a history and the natural course of the care, policies, and laws that have been developed over the years for persons with disabilities. After these introductory chapters, it is broken down into general medical, surgical, and rehabilitation aspects of the care of the Adaptive Athlete, as well as general equipment, such as specialty wheelchairs and prosthetic devices, that are developed to assist these athletes in their specific sport.

The bulk of the text was developed as a go-to resource for various specific sports. The goal is to provide a single source so that someone without any prior knowledge of a specific adaptive sport can utilize to gain an understanding of who is playing (injury types and severity), how the game is played (adapted rules), what equipment these athletes may be using (adaptive equipment), and the common injuries that may occur in this sport. My hope is that anyone who reads this text will have established a firm foundation of the sport and will not be intimidated in providing medical care and coverage for these adaptive sports.

Last, as the field continues to blossom, there are always growing pains and controversies about an equal and fair level of competition. As the technology advances, the governing bodies must consider what a fair accommodation is and what adaptations may provide a competitive advantage.

I would like to thank the numerous authors who have taken their time to make their contributions to this textbook. These authors went above and beyond to provide our readers with the highest-quality and cutting-edge information that will make this text the Gold Standard for Adaptive Sports Medicine.

I hope that you enjoy reading this book as much as I got to help author and edit.

Arthur Jason De Luigi, DO

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I would also like to acknowledge the many persons and organizations who have provided the resources and foundation to allow these persons with disabilities to participate in adaptive sports.

Most importantly, I would like to thank my wife, Beata, and my two children, Oscar and Cyan, for their support and understanding while I worked countless hours on this textbook.

Contents

List of Contributors

Mayur J. Amin, MD MedStar Georgetown University Hospital/National Rehabilitation Network, Washington, DC, USA

Evan Argintar, MD Department of Orthopaedics, Washington Hospital Center, Washington, DC, USA

Michael Auriemma, MD MedStar Georgetown/National Rehabilitation Hospital, Washington, DC, USA

Anthony Beutler, MD Professor, Uniformed Services University, Department of Family Medicine, Bethesda, MD, USA

Daniel H. Blatz, MD Shirley Ryan AbilityLab (formerly Rehabilitation, Institute of Chicago), Chicago, IL, USA

Cheri Blauwet, MD Spaulding Rehabilitation Hospital Department of PM&R, Harvard Medical School, Charlestown, MA, USA

Kevin Blythe, MD MedStar Washington Hospital Center, Georgetown University, Washington, DC, USA

Chelsea D. Brundage, MD Department of Physical Medicine and Rehabilitation, Fort Belvoir Community Hospital, Fort Belvoir, VA, USA

Mary Caldwell, DO Department of Rehabilitation Medicine, MedStar National Rehabilitation Hospital, MedStar Georgetown University School of Medicine, Washington, DC, USA

Patrick Carey, DO US Army, Fort Benning, Columbus, GA, USA

Yin-Ting Chen, MD Department of Rehabilitation, Walter Reed National Military Medical Center, US Army Medical Corps, Washington, DC, USA

Joseph L. Connor Jr, MD Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA

Rory A. Cooper, PhD Department of Rehabilitation Science and Technology, University of Pittsburgh, Pittsburgh, PA, USA

Department of Physical Medicine and Rehabilitation, University of Pittsburgh, Pittsburgh, PA, USA

Human Engineering Research Laboratories, U.S. Department of Veterans Affairs, Washington, DC, USA

Rosemarie Cooper, MPT, ATP Department of Rehabilitation Science and Technology, University of Pittsburgh, Pittsburgh, PA, USA

Human Engineering Research Laboratories, U.S. Department of Veterans Affairs, Washington, DC, USA

Pegah Dehghan, MD Kennedy Krieger Institute, Baltimore, MD, USA

B. Elizabeth Delasobera, MD, CAQSM MedStar Washington Hospital Center, Georgetown University, Washington, DC, USA

William Denq, MD George Washington University, Washington, DC, USA

Shane Drakes, MD Sports Medicine, St Michael, Barbados

Andrew H. Gordon, MD, PhD Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA

Luis Guerrero, MD MedStar Health, Washington, DC, USA

Luis Alfredo Guerrero, MD Sports Medicine and Interventional Spine, Department of Physical Medicine and Rehabilitation, MedStar National Rehabilitation Network, Washington, DC, USA

Nicole Hanrahan, MD Palomar Medical Center Downtown Escondido, Escondido, CA, USA

David Hryvniak, DO, CAQSM Department of Physical Medicine and Rehabilitation, UVA Runner's Clinic, Team Physician UVA Athletics, University of Virginia, Charlottesville, VA, USA

David M. Irwin, DO UPMC Hamot Medical Center, Erie, PA, USA

Joan P. Joyce, CTRS, HFS MedStar National Rehabilitation Network, Washington, DC, USA

Brian Joseph Juriga, DO, FAOASM Sports Medicine Lake Health System, Willowick, OH, USA

Christopher S. Karam, MD RA Pain Services, Mount Laurel, NJ, USA

Tyler Kent, MD Department of Orthopaedics, Penn State Hershey Medical Center, Hershey, PA, USA

Ahmer Khan, DO, CAQSM Baylor Scott and White—Plano, Plano, TX, USA

Jason Kirkbride, MD Department of Physical Medicine and Rehabilitation, University of Virginia, Charlottesville, VA, USA

Jeffrey C. Leggit, MD, CAQSM Department of Family Medicine, Uniformed Services University of the Health Sciences, Bethesda, MD, USA

James G. Liadis, MD Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA

Arthur Jason De Luigi, DO Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA

Patrick Martone, DO Department of Physical Medicine and Rehabilitation, MedStar Georgetown University Hospital/National Rehabilitation Hospital, Washington, DC, USA

Angelie Mascarinas, MD Spaulding Rehabilitation Hospital Department of PM&R, Harvard Medical School, Charlestown, MA, USA

Rajat Mathur, MD Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA

Derick Mordus, MD Department of Rehabilitation, Walter Reed National Military Medical Center, Bethesda, MD, USA

Kevin O'Malley, MD Department of Orthopaedics, Georgetown University Hospital, Washington, DC, USA

Ashley Lazas Puk, ATC MedStar Sports Medicine, Columbia, MD, USA

Lauren Rudolph, MD Division of Physical Medicine and Rehabilitation, University of Utah, Salt Lake City, UT, USA

Alan Schleier, DO Sports Medicine Center, NYU Langone Medical Center, New York, NY, USA

Joseph Scholz, DO, PhD Department of Rehabilitation, Walter Reed National Military Medical Center, US Army Medical Corps, Washington, DC, USA

Joseph A. Sclafani, MD MedStar Georgetown University Hospital/National Rehabilitation Network, Washington, DC, USA

Alexander M. Senk, MD, FAAPMR, CAQSM PM&R Sports Medicine, Minneapolis Veterans Affairs Medical Center, Minneapolis, MN, USA

Mountain Area Health Education Center—Mission Sports Medicine, Asheville, NC, USA

Adam Susmarski, DO Department of Physical Medicine and Rehabilitation, University of Pittsburgh, Pittsburgh, PA, USA

Stuart E. Willick, MD Division of Physical Medicine and Rehabilitation, University of Utah, Salt Lake City, UT, USA

Simon Willis, MD, PGY-3 MedStar National Rehabilitation Hospital, MedStar Georgetown University Hospital, Washington, DC, USA

YouaPa Susan Yang, MD Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA

Ashley D. Zapf, MD Andrews Institute, Gulf Breeze, FL, USA

Craig Ziegler, MD Department of Orthopedic Surgery, Washington University, St. Louis, MO, USA

Monica K. Zillen, DO Lake Erie College of Osteopathic Medicine, Erie, PA, USA

Part I

Adaptive Sports Medicine: History, Technology and Biomechanics

History of Adaptive and Disabled Rights within Society, Thus Creating the Fertile Soil to Grow, Adaptive Sports

1

Joseph Scholz and Yin-Ting Chen

History of Adaptive Sports and Disabled Rights Movement

The history of sports for individuals with disabilities cannot be fully understood without discussing the *disabled rights* movement history. The disabled rights movement in many ways parallels various civil rights movements of the last 200 years. It is a series of historic changes took place starting in the late eighteenth century that led to significant advancement in the recognition, acceptance, and civil rights of people with disabilities. In addition, there were several events, organizations, and movements progressing in separate but parallel lanes. These movements converged resulting in a cohesive and mostly seamless pathway from childhood recreation and competition to team play and elite-level completion—from the Special Olympics, to Paralympics, to athletes with bilateral lower extremity limb deficiency competing against able-bodied athletes in the London Olympics in 2014.

J. Scholz, DO, PhD (✉) • Y.-T. Chen, MD
Department of Rehabilitation, Walter Reed National Military Medical Center, US Army Medical Corps, Washington, DC, USA
e-mail: scholzjo@gmail.com; ychent@gmail.com

Before It All: When Disability Was Criminal

It is important to remember that the current living standard and longevity were not available 2–300 years ago. As life was very difficult for the general population, with life span shorten by disease, hard labor, and lack of effective medical treatment and preventative medicine, these factors had even greater impact on those with physical or mental disabilities. For those who survived disease and poverty, most would live on the margins of society and the shadows of their family's care. Prior to the 1700s, there is scant evidence of general references to disabilities in literature other than diseases, disfigurement, and battlefield wounds. In the 1780s, English surgeon Edward Alanson made advances in the surgical techniques of amputation, leading to faster recovery, lower infection rates, and improved overall survival. These surgical modifications in turn led to increases in the population of "healthy adults" with amputations [1]. In 1784, famed French linguist Valentin Haüy realized that, contrary to the general consensus, blind and deaf people *could* reason. He called for the end of barbaric conditions commonly subjected to blind people and went on to create the Institution for Blind Children. Haüy was considered the "father and apostle of the blind." Haüy also discovered that sightless persons could read texts printed with raised letters, and this work was furthered by one of his students named Louis Braille, which we

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_1

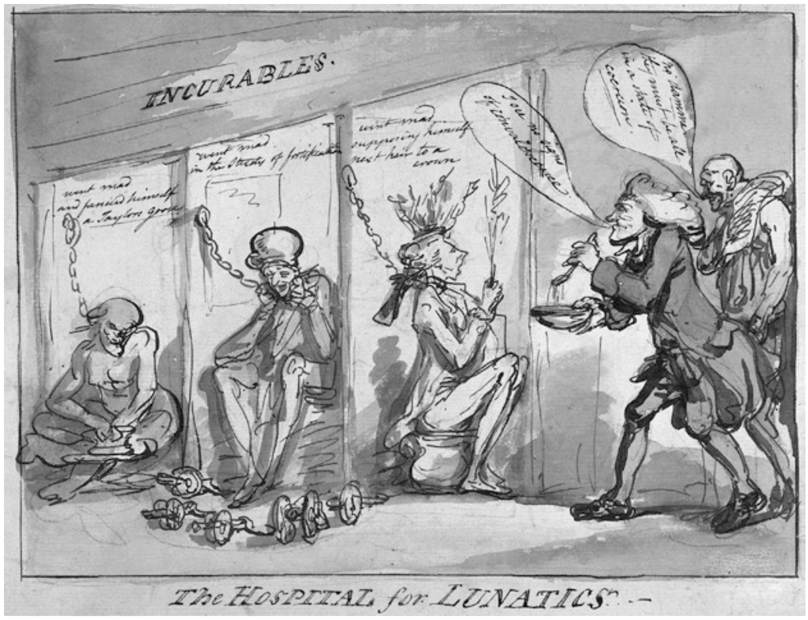


Fig. 1.1 The hospital for lunatics. Bethlem Hospital, London: the incurables. More from english-heritage.org.uk/

now know as the Braille alphabet [2]. In 1793, physician Philippe Pinel removed the chains from people with mental illnesses in the *Bicetre* asylum in France; some of the interned were chained to walls for more than 30 years. This release of people with mental illness from incarceration led to the awareness that they were different from criminals, and what they needed was sympathy as well as a different approach to healing [3] (Fig. 1.1).

Early Wars and the Advance of Disabled Rights

These incremental recognitions of the civil rights of people with disabilities in Europe and the United States eventually took a step forward through formal codification in a series of public laws. On July 16, 1798, the newly formed United States of America passed the Military Disability Law—the first of its kind. President John Adams signed the act for the "relief of sick and disabled seamen," to provide soldiers, marines, and seamen who were dismissed from the military with a small one-time allotment for their limb loss or injuries and to assist them reentering into society [4]. The work in Europe started in the previous century began to shed the commonly held idea that people with mental and physical illness were not possessed or invaded with demons but had medical problems. That coupled with the advances in medicine and education furthered the understanding of persons with disabilities. In the 1860s, Dr. William Little made the first step toward identifying cerebral palsy (CP, or spastic diplegia) by describing children with stiff and/or spastic muscles in their arms and legs. Little also correctly guessed that the condition is caused by lack of oxygen during gestation or birth [5].

Between 1815 and 1817, formal education for those who were deaf and hearing impaired was developed in the United States by Thomas H. Gallaudet. Gallaudet traveled to France in 1815 and learned how to teach deaf individuals to communicate using new *system of hand signals*. Upon his return, he founded the "Connecticut Asylum for the Education and Instruction of Deaf and Dumb Persons" in Hartford, Connecticut, on April 15, 1817. Significant for marking the beginning of American efforts to educate people with disabilities, it is the first permanent school for individuals who are deaf in America, now called the American School for the Deaf [6] (Fig. 1.2).

The Civil War was a time of great upheaval in the United States and inflicted the greatest death toll on our society by the volume of those killed—approximately 750,000 casualties, which represents around 2.5% of the total US population. This amount was greater than any other war in our his-

Fig. 1.2 American School for the Deaf [6]

tory. Conservative estimates placed the total number of amputations from the four-year war at around 30,000 in the Union Army alone. This event brought "acquired disability" issues to the American consciousness as those otherwise healthy veterans returned to their homes and tried to again become productive members of the society. The public recognized the obligation from society toward those who have served and protected them, and the US government responded by creating the *Great Civil War Benefaction* program to provide prostheses to all disabled veterans. This government support led to a boom in prosthetic development and manufacturing; thereby it effectively created the prosthetic industry [7] (Fig. 1.3).

Fig. 1.3 Civil War bilateral upper limb amputee, with advanced prosthetic limbs, Pinterest: https://s-media-cache-ak0.pinimg.com/736x/5c/26/2b/5c262b3121a84d05b72d617721ae1473.jpg

After World War I, several laws were enacted recognizing for the first time the country's obligation to individuals injured in service and building on the work done after the civil war for veterans; specifically the Smith-Hughes Act of 1917 established the Federal Board of Vocational Education with the authority and responsibility for vocational rehabilitation of disabled veterans [8]. Later the Smith-Sears Veterans Rehabilitation Act of 1918 (also referred to as the Soldier's Rehabilitation Act) expanded the role of the Board to provide services for vocational rehabilitation of veterans disabled during World War I. Then, in 1920, the Smith-Fess Act (referred to as the Civilian Rehabilitation Act) began the rehabilitation program for all Americans with disabilities patterned after the Soldiers Rehabilitation Act [9]. It established the Federal-State program in rehabilitation and provided funds to states for primarily vocational services, including vocational guidance, training, occupational adjustment, prosthetics, and placement services. Additionally, the first department of physical medicine and rehabilitation was started in 1929 at Temple University Medical School by Dr. Krusen [10]. Though there had been physicians who specialized in physical rehabilitation (then known as physical therapy physicians), there were no formal training centers or residency. He moved to the Mayo Clinic to start the first residency in 1936, graduating the first resident-trained physician in the field in 1939. In 1947, the first board of physical medicine specialty was given by the newly recognized American Board of Physical Medicine and Rehabilitation (AAPMR) [11, 12] (Fig. 1.4).

Fig. 1.4 Poster, work programs. https://upload.wikimedia.org/wikipedia/commons/1/14/WPA-Work-Pays-America-Poster.jpg

The Great Depression and Disabled Rights

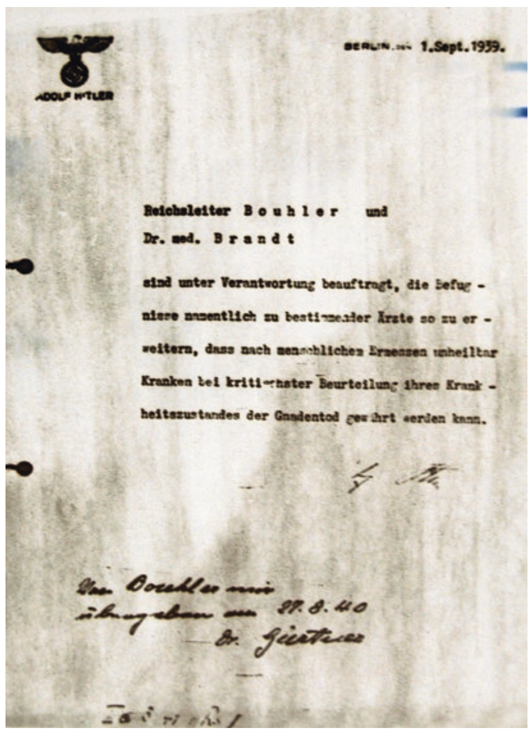
The next major stride in the advancement of the rights of the disabled person was the signing of the Social Security Act (SSA) in 1935 by President Franklin Delano Roosevelt, which included a clause to establish a program of permanent assistance to adults with disabilities. The SSA established federally funded old-age benefits and funding to states for assistance to blind individuals and disabled children and extended existing vocational rehabilitation programs [13]. Additionally, during the Depression, there was a jobs program to get the county working again. The Works Progress Administration (WPA) gave jobs and vocational skill training for the unemployed. However, a poorly applied policy that required people with disabilities requesting employment with the WPA to be labeled with "PH" for "physically handicapped" led to a nine-day sit-in at the Home Relief Bureau of New York City. Three hundred members of the *League for the Physically Handicapped* staged this action that eventually helped secure several thousand jobs nationwide for disabled people. This sentinel event was significant because it marks the first time people with disability took action into their own hands and won [4] (Fig. 1.5).

WWII: German Atrocities and Post-War Benefits for Disabled Veterans

Just when people with disabilities were making great strides in the United States, great crimes were being committed against humanity on the other side of the Atlantic Ocean. Hitler's Nazi program *Aktion* T4 killed thousands of people with disabilities in the name of euthanasia for "life unworthy of life." An estimated 75,000–250,000 people with intellectual or physical disabilities were systematically eradicated from 1939 to 1941 through various methods, including gas and starvation [14]. After the program was discovered at the end of the war, the horror of this program helps slow the eugenics movement in the rest of the western world. Eugenics programs were founded on the philosophy of improving the

Fig. 1.5 Franklin D. Roosevelt signs the G.I. Bill; June 22, 1944, almost 10 years after signing the WPA. FDR Library Photo Collection. NPx. 64-269

genetic composition of the population, resulting in laws passed to prevent people with disabilities from moving freely, marrying, or having children. Further actions based on this philosophy lead to the institutionalization and/or forced sterilization of many disabled adults and children. Though, it is important to note that sterilization was continued well into the 1970s as a form of treatment and control [4, 15] (Fig. 1.6).


ADOLF HITLER

BERLIN, den 1.Sept.1939.

Reichsleiter Bouhler und
Dr. med. Brandt

sind unter Verantwortung beauftragt, die Befugnisse namentlich zu bestimmender Ärzte so zu erweitern, dass nach menschlichem Ermessen unheilbar Kranken bei kritischster Beurteilung ihres Krankheitszustandes der Gnadentod gewährt werden kann.

Von Bouhler mir übergeben am 27.8.40 Dr. Gürtner

Fig. 1.6 The Action A-4 Order from Adolf Hitler, by Marcel—own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=3690975

In 1940, the National Federation for the Blind formed to advocate for legislative reforms to benefit the blind. The American Federation of the Physically Handicapped was the first cross-disability national political organization to urge an end to job discrimination and lobby for legislation. As WWII raged on, the casualties were mounting and the effect of the workforce was being felt. During the war, in 1943, the LaFollette-Barden Vocational Rehabilitation Act added physical rehabilitation to the goals of federally funded VR programs providing funding for some healthcare services [9]. Then in 1944, Col. Howard Rusk, M.D., began a rehabilitation program for disabled airmen at the US Army Air Corps Convalescent Center in Pawling, New York, where he began a rehabilitation program for disabled airmen. First dubbed “Rusk’s folly” by the medical establishment, because it is still not an official specialty, his program was considered a huge success and was duplicated around many of the Army medical hospitals at the time. In 1947, rehabilitation medicine became a new medical specialty known as physiatry [1, 11, 12, 16] (Fig. 1.7).

Fig. 1.7 Dr. Howard Rusk and Roy Campanella. By Roy Campanella, 2016

Fig. 1.8 University of Illinois student from 1940 to 1950s, with stair ramp, after WWII. University of Illinois archives, 2016

In 1946, the Hill-Burton Act authorized federal grant monies for the construction of hospitals, public health centers, and health facilities for the rehabilitation of people with disabilities. Conscientious objectors, who served as attendants at state mental institutions rather than in combat during the war, founded the National Mental Health Foundation, exposing the horrid conditions at facilities that became catalyst toward deinstitutionalization several decades later [17]. In 1946, President Truman's National Employ the Physically Handicapped Week was an impetus for disability rights advocacy activities. Subsequently, in 1947, the Paralyzed Veterans of America was organized and became the early voice, advocating for disability rights [18–20] (Fig. 1.8).

1960s: Women's Rights Movement, Civil Rights Movement, and Disabled Rights Movements

In the 1950s and the 1960s, the movement for the disabled rights started to pick up tempo at the national level, as series of infrastructure initiatives put *accessibility rights* in public view. Post war and modern building designers and builders started setting accessible standards across the country. With thousands of returned veterans with physical disabilities, as well as the polio epidemic survivors, and other people with disabilities started asking for access to public buildings, it led to the launch of the *barrier-free* movement. It combined effort between private entities and the government, the Veterans Administration, the President's Committee on Employment of the Handicapped, and the National Easter Seals Society, and the Rehabilitation Center at the University of Illinois contributed to the development of national standards for barrier-free buildings [21]. The first accessibility standard, "Making Buildings Accessible to and Usable by the Physically Handicapped," was published in 1961 by the American Standards Association. In 1963, the Federal government set aside funding for disability infrastructure support to help local governments to meet and to adapt building to new standards. Yet, even with all that support, it took 10 years for forty-nine states to adopt accessibility legislation by 1973 [22]. The final push by the government to open up access to public buildings to people with disabilities was in 1968, the Architectural Barriers Act [23]. This mandated the removal of what is perceived to be the most significant obstacle to employment for people with disabilities—the physical design of the buildings and facilities on the job. The act required that all buildings designed, constructed, altered, or leased with federal funds be made accessible, because if you cannot easily enter a building, then you cannot expect to be employed.

In the 1970s, the protest movements of the 1960s of the Vietnam War, women's rights, and civil rights movements created the human capital that would be utilized by the disability rights community. In 1970, educator and disability activist Judy Heumann sued the New York City Board of Education when her application for a teaching license was denied. The stated reason was the same originally used to bar her from kindergarten nearly 20 years earlier that "…her wheelchair is a fire hazard" [24]. In 1973, Section 504 of the Rehabilitation Act made it illegal for public entities to discriminate. All federal agencies, public universities, and other public institutions who were receiving any federal funds could not discriminate on the basis of disability [9, 22]. This law is considered by many in the special education field as the turning point for including people with disabilities in all areas and levels of education and beyond. Then in 1974, some of the more arcane laws came to an end, specifically the removal of last of the "ugly laws." These inhumane laws existed for many decades, designed to clean the streets "unwanted elements of society" or at least to hide them from public view. An example: "If a beggar had disability—was paralyzed, or was blind—and if crowds would gather around, the police would come and if the people were getting upset," [it was ok to arrest] the offending person (R). What was unthinkable now existed in Chicago just 31 years before this book was written [4, 25] (Fig. 1.9).

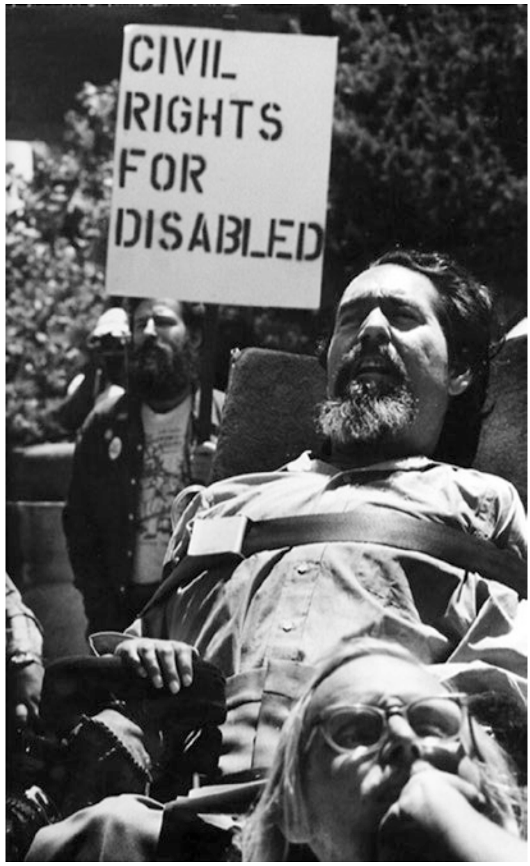


Fig. 1.9 Ed Roberts, protesting access to UC Berkeley, 1963. http://www.nilp.org/about-us/history/2016

Rights to Education

The right to public education for people with disabilities came into the forefront in 1962 when Mr. Ed Roberts, a young man paralyzed with muscle wasting due to polio, was turned down for admission at the University of California, at Berkeley, solely because of his disability. In his pursuit to get the decision overturned and attend school, he became the father of the Independent Living Movement and later helped to establish the first Center for Independent Living (CIL) in Berkeley, California [26]. This right was furthered when the Mental Retardation Facilities and Community Mental Health Centers Construction Act passed in 1963 [26, 27]. The Act provided funding for developing state developmental disabilities councils—advocacy systems. Furthermore, because this legislation funded universities to do research in this area, they generated a lot of data and experts with interest in the education of persons with disabilities. In 1965, Title XIX (19) of the Social Security Act established a cooperative Medicaid and, for the first time, provided assistance with medical costs for low-income individuals with disabilities [18, 22, 28].

The next 30 years were a series of laws that built on each other to provide access to education for all. The Education for Handicapped Children Act of 1975—now called the Individuals with Disabilities Education Act (IDEA), which guarantees a free, appropriate, public education for all children with disabilities in the *least restrictive* environment. Before this, most special needs classes were segregated "special self-contained classes." The Technology-Related Assistance for Individuals with Disabilities Act of 1988 was passed which provided funds for assistive technology and increased access to, availability of, and funding for assistive technology through state and national initiatives. Creating much of the assistive technology computer interfaces we use today, such as text-to-speech, speech-to-text, adaptive keyboards, tablets, joysticks, and track pads; changing the interfaces to computers and the new technologies—thus assisting bridging the gaps between intellect, communication and access. These results and laws dramatically changed the landscape of local schools throughout the nation; before, districts were not "required" to spend over the yearly per pupil amount that they spent on "regular child's education" for "a special child's education," thus creating a very limited method to pay for anything extra or appropriate [9, 15, 18, 22] (Fig. 1.10).

In 1990, the Americans with Disabilities Act (ADA) was signed into law by President George H. W. Bush alongside its "founding father," Justin Whitlock Dart, Jr. Dart Jr. was a polio survivor and disability rights advocate who in 1954 graduated with a degree in history and education from the University of Houston, in Texas, and was denied a teaching license due to his disability. The ADA was the national policy that mandated civil rights ending the centuries-old discrimination of people with disabilities [29].

Fig. 1.10 Protesters march in Washington, DC, in March 1990 as part of a campaign urging the House of Representatives to move ADA legislation

Then, in 1995, Christopher Reeves, the movie actor who played Superman in *Superman, The Movie*, was paralyzed in a horse-riding competition, sustaining a severe vertebrae fracture that paralyzed him from the neck down. Because of the timing with recent advanced airway management in first responders, his stature as a movie star, and he and his wife's activism, he brought attention to people with spinal cord injuries (SCI). To this day, the Christopher Reeves Foundation is a major contributor in SCI education and research [30]. As basic civil rights became more commonplace, people with disabilities started to want and demand inclusion into doing eveyday events—such as sport. In November 1999, a US District Court judge issued an emergency court order telling the Lawton, Oklahoma, Evening Optimist Soccer League to allow Ryan Taylor, a nine-year-old with cerebral palsy, to play in the league. His walker, also referred to as a safety hazard by the defendants, was padded during games, and the boy played on [31].

So, in that quick two-hundred-year sprint, we went from chaining the mentally ill and deaf to walls as criminals, to guaranteeing that they have equal access to buildings, to providing federal money for assistive technology, and finally mandating they have access to education and now sports. It took the separate movements of veteran's governmental benefits program, the social safety net program of the Great Depression, the rights movements—both civil and women's—to achieve the rights the people with disability enjoy today, and it would become the foundation for the development of adaptive sports movement.

The Development of Organized Adaptive Sports: Many Paths Toward the Same Goal

The development of adaptive sports is a story of convergence of multiple movements. By the time disabled rights had been firmly established, people began turning toward other needs of disabled people. These needs include sport participation for people, as a natural healthy part of living life with early efforts placing value on sport/recreation in society; sport and play for children with special populations; sport as part of rehabilitation therapy; sport for the disabled from accidents, war, or disease; and sport for the disabled as competition. All of these areas of need came together as what we see today, a seamless path from learning to ambulate, to therapeutic play, to organized sports for individuals with a spectrum of abilities, from fully able-bodied to severely limited (Fig. 1.11).

Fig. 1.11 Galen treating a wound with a lance grit. Wikipedia commons (2016). https://upload.wikimedia.org/wikipedia/commons/2/2f/Treatment_of_wound_with_lance_grit.jpg

Physical Activity for Rehabilitation

The benefit of exercise was well recognized by ancient cultures such as the Greek and Roman. Galen (129–210 AD) described the benefits of exercise in his work *De Sanitate Tuenda*. In the twelfth century, the Spanish physician Moses Maimonides spoke of "exercise as a protective factor confronting illness" (Posner 1998). The development of sports and competition is long and beyond the scope of this chapter, but the evolution of physical activity and sports as an active means of rehabilitation is attributed to the Swedish scholar Per Henrik Ling (1776–1839), who created a system of *medical gymnastics* at the University of Stockholm. This model himself after he was successful at curing himself from “rheumatism and paralysis” through the practice fencing and gymnastics” [32, 33]. This model was further refined by Ernst J. Kiphard defining the meeting point between pedagogical and therapeutic concepts and further four specific subdisciplines within this field: “*Heilpädagogische Leibeserziehung*” (remedial, corrective, or adapted physical education), “*Behindertensport*” (sports the disabled), “*Sporttherapie*” (sports therapy) referring to physical activity and sports as an active means of physical rehabilitation, and “*Psychomotorische Erziehung/Therapie*” (psychomotor education/therapy for physical activity and sports as an active means for psychosocial rehabilitation) [32, 33] (Fig. 1.12).

The terminologies evolved over time after they arrived in the United States from *corrective gymnastics* to *sports for the handicapped* in the 1930s, *Special Physical Education* in the late 1950s and 1960s, *adapted physical* in the 1970s, and, finally, *adapted physical activity*

Fig. 1.12 Father of modern physical education. https://upload.wikimedia.org/wikipedia/commons/8/8f/Pehr_Henrik_Ling.jpg

(APA). Today, according to Sports and Development, an International Platform on Sport and Development organization, APA has become “the profession, the scholarly discipline and field of knowledge, and the service delivery, advocacy and empowerment systems that have been created specifically to make healthy, enjoyable physical activity accessible to all and to assure equal rights to sport instruction, coaching, medicine, recreation, competition and performance of persons with disabilities” [34]. APA provided a mean for people with disabilities to improve their functional status and quality of life, improve physical and mental well-being, improve self-confidence, and improve societal integration. Furthermore, for able-bodied people, APA is also a mean to educate, remove stereotypical and discriminatory beliefs, leading to better understanding and further breakdown of barriers.

The development of APA was the result of international effort. The UNESCO (United Nations Educational Scientific and Cultural Organization) adopted in 1978 the International Charter of Physical Education and Sport for “the purpose of placing the development of physical education and sport at the service of human progress, promoting their development, and urging governments, competent non-governmental organizations, educators, families and individuals themselves to be guided thereby, to disseminate it and to put it into practice” [35]. For the first time, there was an international consensus regarding physical education and sports as a fundamental right for all people. The Charter also outlined specific goals to ensure that physical education and sport would be a part of all education systems that physical education and sports programs are designed to meet individual and societal needs, with adequate equipment and qualified support staff, as well as calling on the support and development of APA by national institution and international cooperation [35]. In 2002, United Nations Inter-Agency Task Force on Sports for

Development and Peace was convened, and the First Conference on Sports and Development was held in Switzerland on 2003. In 2008, the IOC and the UN established collaborative framework to use sports to support the goals of the UN [36]. The response in the United States was the passing of the Individual with Disabilities Education Act (IDEA) Amendment of 1997, an amendment to the Education for All Handicapped Children Act. In addition to providing special education at no cost to parents or guardians, IDEA mandated instruction in physical education as a direct service to be provided to all children who qualify for special education (as opposed to related services mandated by previous legislation) in the least restrictive environment (LRE), for the development of physical motor fitness, fundamental motor skills and pattern, as well as skills in individual and group sports [37]. With international recognition of the importance of APA, laws like IDEA laid the foundation and the mean for children with disabilities to benefit from sports participation resulting in a new generation of children growing up with the benefits from sports participation and *expecting* sports participation as a right. This new generation would become one of the driving forces behind organized adaptive sports.

Evolution of Sports from Recreational to Competitive: The Development of Paralympics

Recreational and therapeutic adaptive sports had been around for a long time. The deaf community was one of the first communities to pioneer adaptive organized sporting events. In 1888, the "sport clubs for the deaf" in Berlin, Germany, was an early sports club dedicated to deaf people [28]. With the improvements in deaf education in France in 1920, the deaf community continued to gain momentum, and by 1924 the first International Silent Game, a deaf version of the Olympic Games, was held in France. The game organizers

Fig. 1.13 Early advances were in the sport of skiing. disabledsportsusa.org

Eugene Rubens-Alcais and Antoine Dresse successfully attracted nine nations, including six official national federations already in existence, to participate in the Games. This event was quite successful and held every 4 years. Now referred to as the Deaflympics, it is sanctioned by the IOC to occur every 4 years. The Deaflympics is considered the oldest continuously running event for persons with disabilities [38] (Fig. 1.13).

Similar to the Deaflympics, there were two other movements borne of the need to provide recreation and sports as therapy for disabled people. One was for the mentally retarded (now referred as "intellectually challenged") and the cerebral palsied children; both groups were organized by their parents wanting to provide recreational and therapeutic resources that were then missing for their children. The Special Olympics (1950–1960) was founded by Eunice Kennedy-Shriver, dedicated to serve people with intellectual disabilities. Eunice Kennedy-Shriver became passionate about the cause because of her experience with her sister Rosemary, who was intellectually challenged. Eunice grew up with Rosemary playing all sorts of sports and activities, but she realized that these opportunities were limited for most people with intellectually disability. Wanting to give all people with intellectual disabilities the same opportunities, in 1962, Kennedy-Shriver and her friends organized and invited young people with intellectual disabilities to "Camp Shriver." It began humbly as simple backyard activity day, but the movement caught on quickly and grew with momentum as like-minded people joined her cause. By 1968, the First International Special Olympics was held in Soldiers' Field in Chicago, Illinois, USA [39, 40]. Today it is known as Special Olympics International, and it is the world's largest sports organization for children and adults with intellectual disabilities, serving more than 4.4 million athletes in 170 countries and holding up to 70,000 events a year [41]. The events for the Special Olympics run year-round and are not held in conjunction with The Olympic Games. Special Olympics World Game is held every 2 years and alternates between summer and winter games.

While grass roots advocacy was the driving force that led to the founding of the Special Olympics, the formation of the organization to serve people with cerebral palsy (CP) was the result of high-level orchestration. As international efforts throughout the 1950s and 1960s led to the formation of various groups to serve people with disabilities, such a group did not yet exist for people with CP. In 1969 in Dublin during a Rehabilitation International conference, eminent rehabilitation Dr. Arie Klapwijk from the Netherlands spoke of his experience working with people with CP. His passion ignited support among key organizers, and together they formed the first iteration of ICPS, International Cerebral Palsy Society. A Sports and Leisure Group was soon formed within the ICPS by 1972. ICPS evolved overtime, acquiring advice and expertise, and in 1978 the Cerebral Palsy International Sports and Recreation Association, or CPISRA, was formally created [42]. It is currently composed of 59 national members and three associations and is a member organization of the International Paralympic Committee. CPISRA is the governing body for the sports of football 7-a-side, boccia, and race runner [43].

Finally, there was also the development of contest for people with other forms of disabilities, which would eventually lead to the founding of the Paralympics. Though not well known, the earliest documented organized event was the Cripples Olympiad in 1911, held in St. Louis, United States [44]. Other events evolved from the need for rehabilitation for wounded veterans. After the WWII, with the nascent development of antibiotics and modern surgical techniques, there was an increased numbers of soldiers surviving horrific injuries and returning home with lasting physical impairment. Recognizing the need for rehabilitation, Neurologist Dr. Ludwig Guttmann at the Stoke Mandeville Hospital in Buckinghamshire, Britain, initiated a new program to use "sport as a component of rehabilitation" and organized the Stoke Mandeville Games in 1948. As all of the contestants participated in the events in wheelchairs, the game came to be known as the "Wheelchair Games." It is considered the first Olympic-style games for the physically disabled. Dr. Guttmann "tied" his Games to the Olympic Game, which were happening in London at the time in order to draw attention to the rehabilitative progress of the war veterans. By 1952, more than 130 international competitors participated in the game. Given its success, it was recognized by the IOC and was held alongside of the 1960 Summer Olympics Game, and in 1984 it became recognized as the Paralympics Games. Today, Paralympics is organized by the International Paralympics Committee. Its mission is to "enable Paralympic athletes to achieve sporting excellence and inspire and excite the world," as well as to promote the Paralympic values and create opportunities for all persons with disability in all athletic levels [45]. There have been 14 summer games and 11 winter games. The 2012 London Paralympic Summer Game drew 4302 athletes from 164 National Paralympic Committees to participate in 503 events from 20 different sports. The 2014 Sochi Paralympic Winter Game saw athletes from 45 National Paralympic Committees compete in 72 medal events from five winter sports. The Paralympic Games has become the ultimate stage equivalent to the Olympic Game and a source of inspiration and a platform of achievement for disabled athletes (Fig. 1.14).

Fig. 1.14 Stoke-Manville wheelchair games led by Dr. Guttmann. http://www.disabilitysport.org.uk/history.jpg

Disabled Sport USA, Becoming the Largest Organization in the United States, from Humble Beginnings

While the initial developments of organized disabled sports were primarily in winter sports, the movement has now blossomed into year-round recreational activities with various levels of competitive sports. There are now multiple professional organizations dedicated to developing physical fitness programs for people with disabilities, the provisioning of adaptive programs, as well as advocacy for people with disabilities in relation to sports and recreation [20].

The development of adaptive skiing was one of the first important movements in the history of adaptive sports in the United States, and it all started with Jim Winthers, a WWII veteran who served on the famed Skiing 10th Alpine Warfare Team of the US Army 10th Mountain Division. As an avid and skilled skier, Winthers taught other WWII veterans who had sustained leg amputations to ski on one leg while he was working on a ski ranch after the war. One of his students was Jim Graham, a former skier whose leg was amputated due to cancer, and together Winthers and Graham began teaching adaptive skiing techniques in skiing clinics. Graham eventually became the first certified ski instructor with a disability. Their work led to increased interests of skiing in the disabled sports community. In 1967, one of the first disabled sports organizations in the US history was founded—the National Amputee Skiers Association (NASA). It later became the National Handicapped Sports and Recreation Association (NHSRA). Several of Winthers' students went on to move the adaptive skiing movement to new heights: Ben Allen established the first official handicapped ski program, known as the Haystack Chapter of the National Inconvenienced Sportsmen's Association. Doug Pringle became the president of Disabled Sports USA Far West; he went on to greatly expand the NASA from 6 to 25 chapters, expanded *Learn to Ski Clinics*, and authored numerous manuals about disabled skiing. In 1988, the Professional Ski Instructor Association (PSIA) voted to recognize NHSRA's Adaptive Ski Instructor Certification program. Kirk Bauer was the Executive Director of Disabled Sports USA, a leader in the New England Handicapped Sportsmen's Association handicapped teaching program, and went on to lead the NHSRA-expanding programs to include summer sports and fitness programs. The impact of their movement rippled beyond just adaptive skiing. By 1994, NHSRA was renamed Disabled Sports USA (DS/USA), which now includes 91 chapters in 36 states, and oversees multitudes of adaptive sports programs beyond adaptive skiing [20].

Leveling the Playing Field: Adaptive Athletes in Able-Bodied Events

The development of disabled sports has come full circle by now. It started as a means for people with disabilities to attain socialization and gain acceptance, to a means of recreation and rehabilitation, and now similar to its counterpart of amateur national and international competition adaptive sports have become a venue for serious athletes competing at the highest level in their perspective field. It is important to realize that though the movement has only reached public prominence in the past decades, adaptive sports have always been ripe with elite athletes capable of competing at the highest level of its nonadaptive counterpart. Many athletes with disabilities have competed in both the Olympics and Paralympics. German-American gymnast George Eyser competed in the 1904 St. Louis games with a wooden left leg, a replacement for the one he lost after being run over by a train as a child. Eyser went on to win the gold in three events (parallel bar, long horse vault, and 25 ft. rope climb), two silvers (pommel horse, four-event all-around), and a bronze (horizontal bar). Hungarian water polo player Oliver Halassy, who was a left transtibial amputee, competed in three Olympic Games from 1928 through 1936 before the creation of the Paralympic Games for disabled athletes in 1948. US swimmer Jeff Float, who was partially deaf, helped the US team win the gold medal in 4 × 200 m relay in the 1984 Games in Los Angeles. Female runner Marla Runyan, who is legally blind, dominated the track-and-field events at the 1992 and 1996 Paralympics, taking gold in the 100 m and long jump before competing in the 1500 m for the 2000 and 2004 Olympics. Others such as South African long-distance swimmer Natalie du Toit, who has left knee disarticulation, placed 16th in the 10 km swim, and Natalia Partyka, a Polish table-tennis player, who was born with a congenital right transradial deficiency, also competed in both the 2008 Olympics and Paralympics [46].

The most recent milestones of adaptive sports were set by Oscar Pistorius. Pistorius became a double transtibial amputee at 11 months of age due to a congenital limb disorder known as fibular hemimelia. Pistorius was an elite runner, setting multiple Paralympics world records in the 100-, 200-, and 400-m events. Pistorius had the aspiration to compete in international able-bodied events, but his effort was hampered when the International Association of Athletics Federation (IAAF) amended its rule in 2007 to ban the use of “any technical devices” that may offer athletes any advantages—a rule that many believed clearly aimed at the pair of J-shaped carbon-fiber “Flex-Foot Cheetah” prostheses Pistorius used. Pistorius eventually prevailed the legal battle and became the first double amputee to become a medalist in able-bodied international track events. The gravity of his participation was best framed by Kirani James, the Grenadian sprinter who won the gold medal: “I just see him as another athlete, as another competitor but most importantly as a human being, another person.” The statement of equality and blindness to disability places Mr. Pistorius’ in the historical position of opening the door for disabled athletes by not only qualifying but also winning in the Olympics. Although some considered Pistorius’ achievement a reflection of current advances in the field of prosthetics, as David James of the Centre for Sports Engineering Research at Sheffield Hallam University commented, “Paralympic athletes could one day run faster than Usain Bolt,” but no amount of prosthetic advancement could replace the athlete. What Pistorius was able to achieve was a testament of the truly elite athletes overcoming their impairment and demonstrating what they are capable of [47]. Obviously, there are only a few elite athletes who can make this transition, but since there are Paralympians who are qualifying for Olympics right now, this hints at a possibility for the future. A future Mr. Craven further predicted to the BBC in May 2014 is that the Paralympics and Olympics could become one event [48] (Fig. 1.15).

Fig. 1.15 Oscar Pistorius, South African sprinter. NBC News, 2015

Conclusion: The Future of Adaptive Sports

The development of adaptive sports is a story beyond people of disability gaining access to recreation and sports. It is a history of people gaining freedom from persecution and discrimination and recognition for their natural rights—the right to dignity, self-respect, and opportunity. It is the product of historical events and changes in medical advances—the wars and the increase of returned veterans saved by advances in medicine—leading to changes in societal perception of disabled people as well as the legislations to protect their rights. It took people working from all fronts: passionate medical providers, dedicated educators, loving parents, aspiring athletes, healing veterans, and average citizens asserting their rights to be and to live their lives with dignity. Sports have emerged as a platform for people to participate in society, to reach higher. In the last half century, we have seen various organizations mature in their scope and operation, allowing more and more people with disabilities to be included and afforded the opportunity. As adaptive sports continue to evolve and integrate into the able-bodied world, and the barriers continue to be removed, perhaps one day the goal of sports will ultimately be realized and we will finally reach a world where everyone is equal without discrimination.

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Wheelchair Sports Technology and Biomechanics

2

Rory A. Cooper, Rosemarie Cooper, and Adam Susmarski

Introduction: The Role of Technology in Wheelchair Sports

Technology is at the very core of wheelchair sports, and its influence not only on sports but on the lives and perceptions of wheelchair users has been tremendous. The sports that rely on speed and agility require wheelchairs and seating systems that are lightweight, responsive, form-fitting, and roll with minimal effort. The basic components of sports wheelchairs are the wheels, casters, footrests, backrest, and seat (see Fig. 2.1). While this seems simple enough, the varieties are nearly endless, and the designs are customized for each individual sport and athlete.

R.A. Cooper, PhD (✉)
Department of Rehabilitation Science and Technology, University of Pittsburgh, Pittsburgh, PA, USA

Department of Physical Medicine and Rehabilitation, University of Pittsburgh, Pittsburgh, PA, USA

Human Engineering Research Laboratories, U.S. Department of Veterans Affairs, Washington, DC, USA
e-mail: rcooper@pitt.edu

R. Cooper, MPT, ATP
Department of Rehabilitation Science and Technology, University of Pittsburgh, Pittsburgh, PA, USA

Human Engineering Research Laboratories, U.S. Department of Veterans Affairs, Washington, DC, USA

A. Susmarski, DO
Department of Physical Medicine and Rehabilitation, University of Pittsburgh, Pittsburgh, PA, USA

For example, a racing wheelchair is made solely for speed and hence uses large wheels, high-pressure tires, small handrims, a long wheelbase, and a forward-leaning bucket seat. Racing wheelchairs are steered by one of three methods, using the handle bars, the compensator, or by doing a wheelie. In contrast, a rugby wheelchair is made for speed, maneuverability, and impact resistance. Therefore, rugby wheelchairs have low bucket seats not too much different from racing wheelchairs, but they have bumpers, casters in the front and back for quick turning and stability, and shields on the wheels to protect them from insult.

In order to meet the needs of a variety of different wheelchair sports, wheelchairs are designed for each particular sport and most commonly custom fitted for each athlete. Sports wheelchairs are much like sports prosthetic limbs; if they do not become one with the athlete's body, then performance is negatively affected. Sports wheelchairs are made from a variety of materials; the basic frame components can be made from high-strength steel (e.g., chromium-molybdenum alloy), aluminum, titanium, and composite materials (e.g., carbon fiber, Kevlar, fiberglass). Sports wheelchairs often use different materials for different components in order to meet the needs of the sport and the user. For example, on a basketball wheelchair, the wheel rims and handrims may be aluminum, the spokes Kevlar, the frame titanium, the bolts and axles steel, and the backrest carbon fiber.

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_2

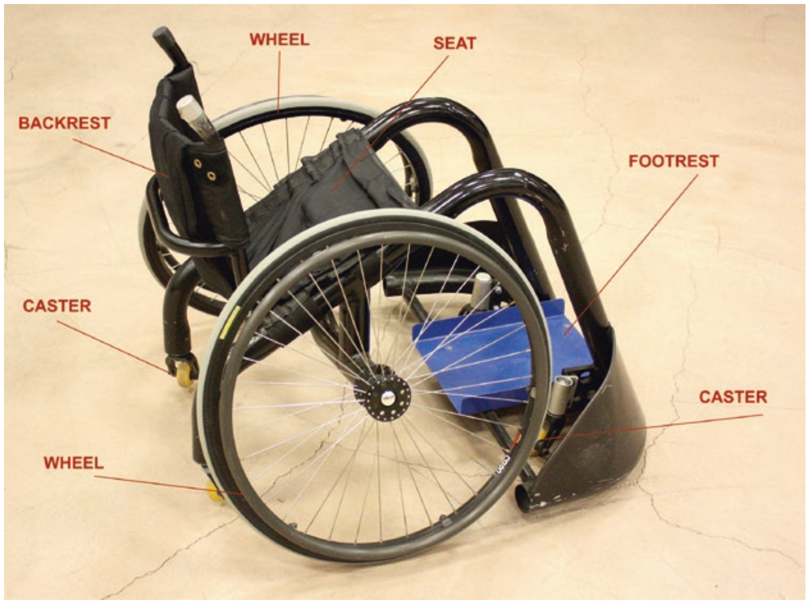

Fig. 2.1 The basic components of sports wheelchairs are the wheels, casters, footrests, backrest, and seat

Brief History of Wheelchair Sports Technology

The exact history of wheelchairs sports is not precisely known. Likely soon after wheelchairs were invented, people using wheelchairs participated alongside friends and family when participating in sports that could be attempted or modified while sitting. There are accounts of service members recovering from wounds during the First World War participating in sports and recreation activities in their wheelchairs as a part of their therapy or for recreation [1]. Sir Ludwig Guttmann is credited with establishing organized wheelchair sports, which eventually led to the Paralympic Games as we know them today [2]. World War II led to tremendous numbers of both civilian and military casualties, as well as remarkable advances in medical treatment and eventually rehabilitation. This as in other wars led to people living with new and more severe disabilities than had been the case heretofore. For example, advances in treatment of post-traumatic shock and the creation of penicillin led to people living with spinal cord injuries for years and eventually decades. The large numbers of mostly young people, many of whom were veterans, living with disabilities had a twofold effect: (1) first, there were a critical mass of people with previously unknown chronic disabilities and (2) they wished to be active and whenever possible leave hospital settings and live in their home communities [3]. This led to two largely parallel movements, at least early on: the creation of multi-sports events such as the Paralympics today and wheelchair basketball—later to become a Paralympic sport. For nearly four decades from the 1940s through the 1970s, athletes competed in nearly the same wheelchair for every sport with minor modifications [4]. During this time frame, people modified their daily-use wheelchairs to improve their sports performance. For basketball, the common modifications were to remove the armrests (sometimes cutting them off), remove the parking brakes, and lower the backrest in order to provide greater freedom of movement for their torso. For wheelchair racing, athletes made many of the same modifications, but in addition they would lower the seat and move the rear axles forward to access a large portion of the handrims to go faster.

In the early 1980s wheelchair sports began to make a tremendous transformation to enter into the modern era as it is now recognized [5]. Athletes began to challenge traditional thinking and the rules of wheelchair sports established primarily by clinicians, rehabilitation administrators, parents, and other well-meaning people. As a part of the worldwide disability rights movement, athletes also wished to take control of their sports, make changes in their equipment, and increase opportunities for competition—some with the goal of achieving parity with able-bodied sports. The biggest impact was that wheelchairs for particular sports began to become available, especially for basketball and racing. To provide some context, at the beginning of the decade, the world record for the mile (1609 m) was a fraction under 5 min, and by the end of the decade, the record had dropped to under 4 min; and by the 1996 Paralympic Games, all of the finalists in the 1500 m were capable of finishing the mile in less than 4 min.

Importance of Seating for Sports Wheelchairs

The seating system is an important interface between the wheelchair and its user and has a direct influence on an athlete's performance and ability to control the equipment and therefore should include the following basic three goals: (1) fit snug and *comfortable like a good shoe*, in order to promote a firm and stable base of support for propulsion and control; (2) provide a stable support to maximize the balance of the user for the sport activity; and (3) reduce the risk of developing pressure sores, skin breakdown, bruising, and other soft tissue injuries [6].

The overall fit of the seating system can easily be checked by asking the user to do a "twist," and the chair should move with the user. The chair will also respond to the user shift in center of gravity (COG) and will "stay" with the user during quick turns and lateral movements especially when operating in tight, narrow, and semi uneven environments [7]. If the width of the seat is too wide, it will result in a loose "sluggish" fit, with the user "twisting" within the seat, which may lead to skin break; or *if the shoe is too big, it causes "blisters."* The length of seat depth should be selected so that there is at least 2–3 in. space between the front edge of the seat and the popliteal area behind the knees. If the seat is too long, the tendency is to slide forward causing the pelvis to rotate posteriorly which increases the risk of developing a sacral sore and back pain. A snug and well-fitted seat allows the shoulder joints to be in a neutral safe position that will enhance the biomechanical efficiency of the upper extremities, therefore reducing the risk of repetition strain injuries.

The orientation of the seat in combination with the back rest support has to be designed and adjusted to provide a stable support to maximize the balance of the user for the sport activity. The hand position in relationship to the elbow angle will show how "low" and/or how "high" the user is sitting in the chair. With the upper arm along the trunk and the hand at top dead center on the push rim, the elbow angle should be 90–120° for efficient self-propulsion. A "low" vertical position (elbow angles $\leq$ 90°) or a "high" vertical position (elbow angles of $\geq$120°) with the user sitting "on top" of the wheels can be corrected by selecting an appropriate height cushion, adjusting the seat dump, and selecting an appropriate wheel diameter [8]. Selection of rear wheel size can provide a wider range of positions, as wheel diameters of 22–26 in. are commonly available. The seat dump is the angle of the seat with respect to horizontal. About 5° of posterior tilt is common; yet a larger seat dump helps to increase pelvic stability by holding the pelvis against the backrest, helps to compensate for decrease trunk stability, and reduces the angle between the thighs and the trunk which helps to improve balance; straps may be used to further hold the user firmly in place. Yet caution should be applied as a larger seat dump may promote pressure sores on the back and affect the COG distribution as it may decrease the rearward stability and increase tipping of the chair; transferring out of the wheelchair will be more difficult. The backrest height should be set as low as possible to provide support to the lower back and allow the upper torso to move freely, however not too high to inhibit movement and biomechanical efficiency of the upper extremities.

The risk of developing pressure sores, skin breakdown, bruising, and other soft tissue injuries for wheelchair sports can be minimized if the athlete recognizes that the same preventative strategies that keep him/her healthy outside the sport with the use of their everyday equipment are the same strategies that will keep him/her healthy with the use of specialized sport equipment [9]. These preventative strategies include recognizing risk, decreasing the effects of pressure, assessing nutritional status, and preserving the integrity of the skin by reducing pressure, friction, and shear forces. Pressure sores commonly occur with prolonged sitting on a bony prominence and hard surface, and the risk can be reduced by increasing the surface area of the seat in contact with the body and providing firm padding that will closely fit the contour of the athlete's body in the seated position for the sport. A snug and well-fitted seat will reduce the friction and shear forces, and straps can further hold the athlete firmly in place. In some cases, the seat is molded to the user to form a custom seating orthotic. Other biomechanical causes of skin breakdown athletes with paraplegia need to keep in mind include pressure from tight clothing or shoes and trauma to insensate lower extremity during transfers.

Of note: it is important to conduct frequent inspections of the equipment and conduct regular maintenance and timely replacement of any worn-out/damaged seat components to reduce the risk of lacerations and injuries.

Wheelchair Slalom

The slalom is an obstacle course race designed for wheelchair users. What began as a simple obstacle course at VA hospitals to help veterans practice on uneven terrain has grown to a competition at the National Veterans Wheelchair Games that is one of the most popular events for athletes, therapists, families, and spectators. This event creates obstacles (only limited by the imagination of the course design team) to simulate everyday mobility challenges a wheelchair user may encounter, such as turns, changes in direction, ramps, curbs, steps, uneven terrain created with robes, planks, ladders, soft terrains such as gravel and sand pits, as well as doors, narrow passage ways, even small tunnels, and so on. The slalom course demands of the athlete speed, coordination, strength, and technique in negotiating the obstacles in the least possible time making as few mistakes as possible.

The design of the course and its difficulty vary depending on athlete's injury classification and type of wheelchair used. For example, for powered wheelchair users, the design of the course will challenge the athletes in precision driving by requiring highly skilled operation of the joystick, head control, chin joystick, sip-and-puff, etc. while skillfully maneuvering the power base through turns, changes in direction marked by cones, over small ramps, and through semi uneven terrain at fast speed with very few mistakes. All athletes are required to wear a helmet and will use their everyday power wheelchairs for competition. Official score keepers are present on the course, and official "spotters" provide for the safety of the athlete.

For manual wheelchair users, the design of the course varies depending on athlete's injury classification and competition category. All athletes are required to wear helmets and most of them will use their own manual wheelchair. No specific type of manual wheelchair is required; however, athletes competing in ultra-light manual wheelchairs, which fit "snug" and with legs and feet strapped securely to the chair, have a better chance to do well in the slalom course. The profile and inflation pressure of the wheelchair tire will have an effect on how well a tire can "grip" an obstacle, for example, knobby tires that are slightly underinflated will provide a nice grip to climb over an uneven obstacle yet will perform slower on flat surfaces during fast turn and change of directions tasks; on the other hand, high-pressure slick tires will be faster on flat surface during turns and change of directions task yet may "slip off" of uneven obstacles. The fine-tuning and selection of "strapping" and "tires" depends on each athlete's abilities and preferences. During the slalom competition, the official score keepers are present on the course with at least four trained "spotters" to provide hands-on assistance for safety to catch athletes from tipping and/or falling onto/off obstacles.

The Super G, or Super Giant Slalom, is a featured event and scheduled on the last day of the competitions to draw the general public to the NVWG. It is the ultimate course designed for a selected group of highly skilled manual wheelchair users, all top three "finalists" who qualified in their individual categories. The competition is very intense and full of energy as athletes "fly" over the most challenging obstacles, with skilled control, precision technique, strength, and high speed in order to beat their competitors' times while having fun with the ultimate goal to be the fastest Super G winner [10].

Wheelchair Basketball

Originating in the 1940s, basketball is one of the oldest wheelchair competitions and is currently played in more than 100 countries around the world [11]. Wheelchair basketball is played by two teams of five players on a regulation basketball court with a hoop on either end and standard markings for both free throws and three point lines. The goal is to work the basketball down the court either individually through dribbling or as a team through passing in order to score a greater amount of points than your opponent by making the most baskets.

Basketball wheelchairs share similar basic features but are additionally adapted based on the athlete's impairment, as well as position. All basketball chairs include a degree of camber allowing for increased agility on the court, greater stability, and protection of the athlete's hands from incidental or direct contact during play. Chairs typically are equipped with both front and wheel casters to prevent the athlete's chair from tipping over as a result of contact or an abrupt change in direction. The athletes are additionally tightly strapped in to the chairs with either straps or even tape in order to prevent the athlete from falling out of the chair during the game (see Fig. 2.2).

Chairs are then adapted to fit the individual athlete based on level of impairment by increasing the height of the seat back and depth of the dump (seat angle) to allow for better trunk control. Chairs may also be adjusted based on position, for example, a higher seat position for forwards and centers for close range shooting versus a lower center of gravity for guards to improve maneuverability and skillful dribbling of the basketball (see Fig. 2.3) [7].

Additional techniques utilized by wheelchair basketball athletes include using one's own inertia by propelling the chair in the direction of the hoop prior to shooting. A skillful athlete may also pin a rolling basketball on the floor to the moving wheel of their chair in order to pick up the ball from the floor using only one hand while maintaining a firm and seated position in their wheelchair (see Fig. 2.4).

On a recreational level the sport has gained an increased and broad following as it allows a

Fig. 2.2 Illustrates a wheelchair basketball athlete's positioning including straps around the patient's trunk and legs. In addition, the forward bumpers and camber of the wheels are well demonstrated from this angle. (Photo courtesy of Marshall Lee Tempest)

Fig. 2.3 Exemplifies the varying heights of the athlete's chairs based on position from an elevated position for the athlete in the back, left of the picture to a lower center of gravity for those athletes on the right. (Photo courtesy of Marshall Lee Tempest)

Fig. 2.4 Shows an athlete using his forward momentum to pass a basketball to teammates underneath the hoop. (Photo courtesy of Marshall Lee Tempest)

Fig. 2.5 A wheelchair basketball athlete shooting a free throw. Rules require the athlete's two main wheels to be positioned behind the free throw line. However, the athlete's feet and front casters may be positioned in front of the line as long as the point of contact of the two main wheels is behind the free throw line. (Photo courtesy of Marshall Lee Tempest)

unique opportunity for both disabled and non-disabled athletes (in wheelchairs) to compete against one another. It isn't uncommon to find a game with a combination of athletes competing on the same court at a local gymnasium or park. The speed, maneuverability, dribbling, and shooting required for wheelchair basketball requires a significant amount of upper body strength and as a result makes the sport inherently challenging for athletes with upper extremity impairment (see Fig. 2.5).

Wheelchair Rugby

Due to the challenges of shooting and dribbling a basketball for those athletes with upper extremity weakness and impairments, players with tetraplegia are at an inherent competitive disadvantage. As a result, wheelchair rugby was created by and is limited to those athletes with tetraplegia or significant upper extremity impairment as an alternative to wheelchair basketball [12]. Wheelchair rugby gained mainstream popularity with the debut of the documentary entitled "Murderball" which featured the United States quad rugby team and exposed the world to the ultracompetitive and often very physical nature of the sport.

The game is played with a volleyball on a rectangular playing area similar to the size and shape of a basketball court. Four players from each team compete on the court at one time. In order to score a goal, a player must carry the ball across their opponent's goal line which is delineated by the baseline of the basketball court on each end. The ball may be carried, dribbled, or passed down the court; however, one player may not carry the ball for greater than 10 s without passing or dribbling (see Figs. 2.6, 2.7, and 2.8). Failure to do so results in a violation and turnover of possession to the opposing team [13].

Wheelchair rugby chair technology is similar to chairs used in wheelchair basketball with adaptations to account for the permitted contact of the support, as well as support the decreased trunk control of the quad athlete. The chairback has a higher back for trunk control, and the chair has a greater degree of dump (seat angle) to prevent the player from falling forward out of the chair with impact, as well as to aid in carrying the ball in the players lap. In order to accommodate for the impact and close contact of the sport, several adaptations are made to the chair to include a metal shroud covering the spokes of the chair in order to prevent an opponent from hooking or impeding the athlete's progress, as well as a forward bumper and sometimes a hook to capture and disrupt the attack of an offensive player [7]. Finally the wheels are set in a notable amount of camber to both improve the agility of the chair and to prevent injury to the player's hands during contact.

Wheelchair Softball

Wheelchair softball is played on a hard flat and level surface with dimensions of 150 ft down each sideline and 180–200 ft to center field [14]. The diamond consists of an outline on the playing

Fig. 2.6 An offensive player breaking away from the pack and dribbling on a breakaway, en route to scoring a goal. (Photo courtesy of Adam Susmarski)

Fig. 2.7 An offensive player takes advantage of the increased dump in his chair to carry the ball down the court, while the defensive player adjusts his positioning to pivot and make contact with the ball carrier in attempts to impede his progress and ultimately dislodge the ball. (Photo courtesy of Adam Susmarski)

Fig. 2.8 A player scoring by crossing the goal line with the ball. In addition the shroud overlying the spokes on the player's wheel and the front bumper surrounding the foot plate is readily identifiable from this view. (Photo courtesy of Adam Susmarski)

surface of a 4 foot circle for second base and semicircle at first and third base (referred to as a defensive circle) with an inner one foot square base within the circle. A defensive player may have only one wheel within the defensive circle to get a player out, while the offensive player running the bases must cross over the inner one foot square base [15]. Teams consist of a competition of ten versus ten players, and the game is played with the larger and often softer 16 in. softball allowing players to play the field without the use of a glove. The exception to the rule for the use of a glove defensively is for tetraplegic players whom may wear a glove on one or both hands [15]. The pitcher throws from a flat straight line drawn on the field, not from an elevated mound.

There is currently not a softball-specific wheelchair design; however, players oftentimes will use a chair similar to those used in wheelchair basketball. As in wheelchair basketball, the increased camber improves the athletes ability to make sudden and sharp turns and movements in response to a batted ball, as well as provide increased stability when rounding the bases or transitioning from catching to throwing the ball defensively. Camber in conjunction with the forward roller bar is especially beneficial to those players playing in the infield and running the bases as it helps protect the players in the setting of contact during the dynamic of the play. Once a player is set in the batter's box, a small Styrofoam or wooden block may be placed behind each of the batter's wheels to prevent the inertia of the swing rolling the batter backward mid-swing as can be seen in Fig. 2.9.

Batters also, depending on preference and injury level, may choose to swing the bat with either both hands or one hand (typically the bottom hand, i.e., right hand for right-handed batters and left hand for left-handed batters). If a player leaves his/her chair for any competitive advantage, e.g., to catch or stop a batted ball, then all baserunners will be awarded two bases [14].

Wheelchair Racing

Wheelchair racing is a sport solely founded in speed. Its singular objective is to cross the finishing line as fast as possible. For all races from

Fig. 2.9 A player batting with a block placed behind each of the wheels to prevent the inertia of the swing rolling the batter backward mid-swing. (Photo courtesy of Adam Susmarski)

Fig. 2.10 Racing wheelchair during a race on a running track

100 m to the marathon (42.5 km), athletes are using essentially the same basic wheelchair design. The key elements to a racing wheelchair are the wheels, frame, seat, and handrims. Nearly all racing wheelchairs have three wheels and use high-pressure tires (racing pressures in the ranges from 160 to 200 psi) (see Fig. 2.10). The front wheels are typically 20 in. in diameter, while the rear wheels are 26–27 in. in diameter depending on the athlete's arm length and preference. Three large wheels help to reduce rolling resistance (i.e., larger wheelchair diameters generally have lower rolling resistance) and to make the wheelchair lighter (i.e., fewer wheels and simpler frame). When viewed from underneath, the frame looks like the letter "T," with the axle tube cross-

ing the tube connecting the front wheel. Racing wheelchair frames are commonly fabricated from aluminum or carbon fiber for minimum weight and maximum stiffness (i.e., attempt to eliminate power loss due to flex in the frame and misalignment of the wheels).

The seat is critical to the performance of a racing wheelchair. Nearly all athletes use a kneeling position with their torso facing forward at an angle between 20 and 45° with respect to horizontal, depending on the ability of the athlete to control their torso and tolerate the positioning. The seat must be form fit; any extraneous movement is lost power to the wheels. A tight seat also permits bringing the wheels in closer to the body, which makes it possible to reduce the camber (camber is the angling of the wheels outward from the frame) and hold the arms in a more neutral position. A neutral position of the shoulders improves power transfer from the user to the handrims and reduces risk of injury to the shoulders.

The arms need to be able to comfortably reach the bottom of both handrims simultaneously for maximum force/momentum transfer. Handrim size is a function of upper body strength, arm length, and hand speed. Athletes with stronger upper bodies can push a smaller handrim diameter; athletes with shorter arms typically must push with a smaller handrim diameter or use a smaller diameter wheel. A larger handrim uses less force but requires greater hand speed in order to achieve the same power output. Power is the product of force and velocity; to achieve the same power that drives the racing chair forward, the handrim can be selected based on the athlete's specific attributes for either arm force generation or hand speed production. The range of handrim diameters varies from 14 to 18 in. Handrims are coated with a high-friction pliable surface in order to transfer maximum power from the arms to the handrims, primarily by avoiding slipping and simplifying the coupling between the hand and the pushrim (e.g., punching the handrim versus grasping the handrim, which is slower due to the time required to grasp and release).

Propelling a racing wheelchair is an art form. When done right, it is beauty in motion and the athlete can achieve a feeling of grace and speed with total control. To develop an efficient and effective stroke takes optimal fitting of the wheelchair to the athlete, proper sitting posture for racing, and frequent rigorous training with attention to detail. It can take years to develop a fluid and efficient stroke, and some people are never able to achieve it. The basics are simple to learn but difficult to master. The stroke begins with the contact phase when the athlete's hands strike the handrims, optimally between 2 and 3 o'clock, transferring momentum from the hands and arms to the pushrim like a boxer delivering a blow. The push phase follows by rapidly extending the arms to transfer power from the arms to the handrim until the hands reach about 7 o'clock. The release phase requires one last effort from the triceps to fully extend the arms and push off of the handrims to propel the hands backward and upward. The swing phase pulls the arms further backward and upward to prepare for the next stroke and to preload the shoulder and chest muscles to spring forward for the next push. The preparatory phase begins with the elbows bending and bringing the arms forward rapidly to gain maximum momentum at contact with the handrims. Top tier racers internalize their stroke and commit it to muscle memory. Once that has been achieved, one can learn the fine points of adjusting for turns, hills, passing, and surging.

Handcycling

Handcycles have been in use for over 100 years [1]. In the beginning they were used as alternatives for wheelchairs on uneven surfaces and unpaved roads. However, it was not until the 1980s that handcycles began to grow popular for racing. As the sport of triathlon grew in popularity, wheelchair athletes joined the spirit and used handcycles for the cycling portion. As the number of handcyclists grew in numbers, the opportunities for racing and touring increased. A benefit of handcycles is that they can accommodate a wide variety of body types and levels of impairments [7]. They have made it possible for people to participate in a healthy sports and recreation activity alongside friends and families.

Fig. 2.11 Upright handcycle used for touring, socializing, and shopping

There are four basic handcycle designs: upright, add-on, recumbent, and kneeling. Upright handcycles are the oldest style designs available (see Fig. 2.11). Basically, they use the same seating position as a wheelchair with the cranks in front of the seat. Upright handcycles are mostly used as a transport device. They are particularly popular in areas where there are bicycle pathways or walking zones in cities; these allow people to use their upright handcycle for socializing and shopping. Add-on handcycles are a fifth wheel that attaches to the front of a person's wheelchair temporarily converting it to a handcycle (see Fig. 2.12). This provides the user with the benefits of an upright handcycle when desired and a wheelchair otherwise. This is beneficial for exercise, for reducing the strain on the arms, and for shopping/socializing.

Recumbent and kneeling handcycles are used for racing or at least for rigorous exercise. When using a recumbent handcycle, the user is positioned nearly flat in the seat just a few inches from the ground (see Fig. 2.13). The rider's legs straddle the front wheel, while his/her head is between the rear wheels. The cranks are position above the rider's chest at a distance that allows the rider to provide power over the largest portion of the 360° crank cycle. The recumbent position lowers wind resistance and allows a rider with little trunk control to push and pull on the cranks while maintaining balance.

In a kneeling handcycle, the rider sits in a forward-leaning position with the shoulders placed above the cranks (see Fig. 2.14). This position is typically used by individuals with lower limb amputations or impairment that maintain their sitting balance and have good trunk musculature. The kneeling position allows the rider to lean into the cranks while pushing downwards providing maximum power, much like a bicyclist. Kneeling handcycles tend to be faster in sprints or on uphill sections due to the ability to apply more power. However, on flat surfaces, the benefits of kneeling and recumbent handcycles tend to balance each other.

Fig. 2.12 Add-on handcycle used to convert a manual wheelchair temporarily into a handcycle for touring, shopping, and socializing

Fig. 2.13 Recumbent handcycle used for racing and exercise

Fig. 2.14 Kneeling handcycle used for racing and exercise

Conclusion

With the increasing popularity of wheelchair sports, there has been a corresponding demand for high-technology wheelchairs designed specifically for each event. When designing a sports wheelchair, it is vitally important to understand the forces acting on the user during an athletic event. Current wheelchair technology allows athletes to compete at the highest levels, and as wheelchair technology improves, so will athletic performance.

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3 Technology and Biomechanics of Adaptive Sports Prostheses

Arthur Jason De Luigi

Introduction

With advances in medicine and an emphasis on maintaining physical fitness, the population of athletes with impairments is growing. There is an estimated 55 million persons with impairments in the United States according to the United States Census Bureau [1–3]. Although the number of people with an impairment who participate in sporting activities is increasing, there are still only about two million recreational and competitive athletes with impairments in the United States [2–4]. Despite an increase in the development of a number of recreational and competitive sports programs, about 60% of the persons with an impairment do not participate in any regular physical activity or sports [5]. Two of the primary factors that limit participation in sports and exercise are lack of awareness and access to all of the opportunities available for athletic participation [5]. It is incumbent upon healthcare practitioners to make every effort to inform these individuals of growing and diverse opportunities and encourage their safe participation through counseling and education.

Participation in athletic and exercise activities is universally beneficial, and several publications have made recommendations regarding the efficacy of regular physical activity [6–8]. It is known that physical inactivity increases the risk of many disease pathologies and is a major risk factor in cardiovascular disease [9–11].

There are clear benefits for participating in exercise and athletic activities. Athletes with impairments demonstrate increased exercise endurance, muscle strength, cardiovascular efficiency, flexibility, improved balance, and better motor skills compared with individuals with impairments who do not participate in athletics. In addition to the physical benefits, the psychological benefits of exercise include improved self-image, body awareness, motor development, and mood. Athletes with impairments have fewer cardiac risk factors, higher *high-density lipoprotein* (HDL) cholesterol, and are less likely to smoke cigarettes than those who are disabled and inactive [3, 12]. Individuals with limb deficiencies who participate in athletics have improved proprioception and increased proficiency in the use of prosthetic devices [3, 13].

Benefits to Participating in Adaptive Sports for Persons with a Limb Deficiency

Physical activity has many specific benefits for the population with physical impairments, including a decrease in self-reported stress, pain, and depression, as well as a general increase in

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine,
Washington, DC, USA
e-mail: ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_3

the quality of life [14]. Participation in physical activity has also shown a positive relationship with improved body image for many persons with limb deficiency [13]. Lower limb deficiency due to amputation or congenital defect does indeed constitute a major physical impairment that can lead to functional and professional disabilities [15]. A commonly referenced survey revealed that persons with lower limb deficiencies had a strong interest in participating in sports and recreation with the majority of respondents indicating that their quality of life could be enhanced if the prosthesis did not limit their ability to move quickly and run [16]. Another survey showed that the 20–39-year-old age group had a similar distribution of interests between high-, moderate-, and low-energy activities. The same survey reported a high ability to perform these activities while using a prosthesis [17]. The information suggests that the prosthesis is no longer the primary limiting factor when participating in desired activities. However, it is imperative to set realistic goals based on the physical capabilities of the athlete of when to begin a transition from a general use to sport-specific prosthesis following supplement endurance training from a deconditioned state [18]. Given the opportunities for participation in sports that are currently offered to persons with a limb deficiency, the demand for new, innovative prosthetic designs is challenging the clinical and technical expertise of the prosthetist.

Limb regeneration of a deficient limb has not yet been accomplished in humans. Although technological advances in prosthetics continue to evolve and may one day surpass human capabilities, a prosthesis cannot exactly replace what the individual was born without or lost in trauma or disease. Aggressive rehabilitation and appropriate prosthetic provision will enhance the ability of limb-deficient individuals to pursue athletic activities. Understanding the biomechanics of the sport and the physical characteristics of the remnant limb is the first step in determining what a prosthesis can provide. The following sections present principles involved in the design of prostheses suitable for sports and recreational activities.

Advances in Sports Prosthetics

General Use Versus Sports Prosthesis: Principles of Design for Prostheses

There can be significant differences between a prosthesis developed for general use compared to a sport-specific prosthesis. Typically, there is planning between the person with limb deficiency, physician, and the prosthetist to determine the appropriate modifications to the general prosthetic design to make it compatible with the given sport.

Standard General Use or Utility Prosthesis

Although the residual limb is undergoing expected shape and volume changes, it is important to consider using the prosthesis for as many activities as possible. In most instances, prostheses that allow the limb-deficient athlete to participate in a wide range of activity, including selected sports, can be designed. Current options, such as elastomeric gel liners that provide socket comfort and skin protection that are required during everyday ambulation can suffice for many recreational activities. Careful choice of the prosthetic foot allows the person with limb deficiency to walk faster and achieve a more equal step length on both sides, thus facilitating recreation and routine walking [19]. The prosthetic foot that has been aligned for comfort and efficiency during walking can still function adequately for intermittent, moderate bouts of higher activity. Although it has been shown that persons with limb deficiency find it difficult to accurately report their activity level versus measured activity level, the focus should be to develop ambulatory skills with a general prosthesis before advancing into sport-specific limbs during the early stages of rehabilitation [20]. Once the person with limb deficiency commits to participation and training for a particular sport, a specific prosthesis or component may be necessary. When a single-use prosthesis is provided, the optimized design facilitates full and potentially competitive participation in the desired activity [21].

Another approach is to utilize the current daily-use socket with additional foot and/or knee combinations. The socket can be coupled with interchangeable distal components that have been selected to facilitate different tasks. A quick release coupler can be provided to permit interchanging knee and foot/ankle components. This alternative, when appropriate, can be more time-effective and cost-effective than multiple individual prostheses [21].

Sport-Specific Prosthesis

When the physician and prosthetist are evaluating the athlete with a limb deficiency for adaptive equipment, it is pertinent to take into consideration several aspects. Compared to the prosthetic device intended for everyday use, sports prostheses incorporate various design modifications that meet the functional demands of the sport. Of particular importance is the weight of the prosthesis, particularly in sports where increased weight may affect speed. Depending on the specific sport, there are other aspects of the prosthesis to consider. There are times where there may be an advantage with a conventional prosthesis rather than a prosthesis with advanced technology for a given individual with limb deficiency. Prescribing prosthetic components that facilitate higher activities is typically based on the experience of the prescribing physician and of the prosthetist [22]. It is useful to clearly understand the functional and biomechanical demands of a specific sport when formulating a prosthetic prescription so that the functional characteristics of the components match these criteria. Participation in most sports can be facilitated by adaptations of conventional socket designs combined with commercially available components, but some activities are best accomplished with unique custom-designed components. Also, during the prescription of a prosthesis, the clinician should consider alignment, prosthetic foot dynamics, shock absorption, and the possible need for transverse rotation [21]. As more persons with physical impairments pursue opportunities to participate in adaptive sports, it becomes imperative that medical providers begin the discussion about these recreational options. The componentry of the prosthesis may vary significantly between the various sports.

Depending on individual choice, patients can opt to participate in sports without a prosthesis. Swimming is one example of an activity in which use of a prosthesis is not always desired. The prosthesis can be used to reach the water and then removed prior to entry. During Paralympic competition, the International Paralympic Committee (IPC) requires that all prosthetics are removed prior to competition. The International Amputee Soccer Association (IASC) requires that all athletes with a lower limb deficiency participate without a prosthesis and use bilateral forearm crutches. In contrast, the Paralympic alpine skiing discipline allows athletes with a unilateral limb deficiency to choose use of a single ski, outriggers, or prostheses; however, athletes with upper limb deficiencies usually compete without using poles. When prostheses are not worn, it is advisable that athletes with limb deficiency wear some form of protection on the residual limb. It can be as simple as using the liner typically used under the prosthesis. However, if the athlete desires increased protection from high-impact falls, then a custom limb protector can be fabricated.

Prosthetic Design Alignment and Componentry

General Alignment for Sports Prostheses

Several studies demonstrate that alignment is not as critical as volume change in affecting skin stress on the residual limb [23–25]. In the context of this evidence, it still remains a critical aspect of optimal sports performance. Alignment of the socket and shank of a lower limb prosthesis critically affects the comfort and dynamic performance of the person it supports by altering the manner in which the weight-bearing load is transferred between the supporting foot and the residual limb. Furthermore, alignment of the lower extremity prosthesis for sports activities may be significantly different than what is optimal for other activities of daily living. Water and snow skiing are good examples of sports requiring increased ankle dorsiflexion. However, when the prosthesis is optimally aligned for these sports, it will not function well for general ambulation. In these instances, either a special-use prosthesis or interchangeable components will be necessary, and it is imperative to educate the limb-deficient athlete on properly change components to protect the limb from misalignment [21].

Biomechanics and Force Reduction in Sports Prostheses

When the multidirectional forces that give rise to pressure and shear stresses are expected to increase because of athletic activity, a socket liner made from an elastomeric gel is often recommended. Patients with conditions such as skin grafts or adherent scars will have a reduced tolerance for shear [26]. For transfemoral limb-deficient athletes, special consideration should be given to the proximal tissue along the socket brim and the ischial tuberosity. Patient comfort can be increased by the use of a flexible plastic inner socket supported by a rigid external frame. This combination simultaneously maintains the structural support and integrity of the socket while allowing for increased hip range of motion because of the flexibility of the proximal portion of the inner socket [21].

The heels of prosthetic feet can dissipate significant amounts of energy during loading [27]. Prosthetic feet have been shown to be capable of dissipating up to 63% of the input energy. Once a running shoe was added, the dissipation capacity increased to 73%. Even with the encouraging capability of the foot to absorb energy, once it has reached its limit, the forces are transferred to the socket and then ultimately the limb. Shock-absorbing pylons can be added between the socket and foot if additional impact reduction is desired. They may be an independent component or an integral part of a distal lower extremity integrated system. Some shock-absorbing pylon systems are pneumatic and easily adjusted by the user; other systems must be adjusted by the prosthetist to provide the optimal amount of vertical travel. The addition of a shock-absorbing pylon may show few quantitative kinetic or kinematic advantages with ambulation, but pylons do show a force reduction during loading response. Furthermore, prosthetic users also reported improved comfort, particularly at higher speeds [28, 29]. It is important to consider that when negotiating a descent on stairs or a step, the transfemoral limb-deficient athlete may gain added effect from an energy-absorbing pylon because of the increased lower extremity stiffness secondary to a lack of shock-absorbing knee flexion of a mechanical knee.

A prosthetic torque absorber component can be provided that will allow up to a 40-degree range of internal and external rotation between the socket and foot. Although multiaxial ankles offer some rotational movement, a separate torque-absorbing component performs this most effectively. There are many torque absorber options commercially available, but none can effectively match or be adjusted to the asymmetrical internal and external torque seen in able-bodied individuals [30]. Even given the importance of minimizing transverse plane shear stress on vulnerable soft tissue, this component should still be considered even though it cannot exactly match the characteristics of the intact contralateral limb [21].

The development and prescription of energy storage and return prosthetic feet instead of conventional feet is largely based upon the experience between prosthetist and athlete with limb deficiency. The clinical decision making for the use of prosthetic feet is not always based upon the comparative biomechanical analysis of energy storage and return and conventional prosthetic feet but also incorporates the feedback of the athlete with limb deficiency. Despite the history of comparative prosthetic literature and continued analysis of prosthetic components, there remains a missing link between the scientific evidence and clinical experience of the medical providers [31]. Although there may not have statistically significant changes in gait or performance parameters, these subtle changes and differences are perceived by athletes with lower limb deficiencies to affect their preferences and perception of foot performance. Variations in prescription may allow for benefits such as greater propulsive impulses by the residual leg that contributes to limb symmetry [32, 33].

Considerations for Various Sport-Specific Prostheses

Running Prosthesis

There are numerous prototypes of running prostheses which have been developed. The most individualized aspect of the running prosthetic is the socket. The socket is formed fitted to the individual amputee to allow direct contact to maximize function and decrease complications. Given the increased energy cost of ambulation in an athlete with transfemoral limb deficiency, there has been limited evaluation of the best knee devices for running. However, running has frequently been performed by lower extremity limb-deficient athletes with single axis, hydraulic, pneumatic, and computer microprocessor knee devices. The majority of the variations are in the type of terminal device. Most running legs will have a flexible keel, which is energy storing. The goal of the flexible keel is to simulate propulsion caused by plantar flexion. There are different tensile strengths leading to a varied amount of kinetic energy stored in the flexible keel, and they can be molded as predominantly linear or curvilinear. There is less kinetic energy being stored in the prosthetic designs with a greater bend in the carbon graphite keel. Therefore, curvilinear flexible keels are utilized for recreational running or jogging. However, the competitive athletes will utilize a linear flexible keel with a less pronounced curve re-creating the foot.

The topic of the comparative kinetic energy in the flexible keel to the human leg is controversial. There is specific concern as to the length of the prosthetic limbs and subsequently the amount of energy stored in the keel. Typically the longer, more linear flexible keels will store the most energy. The more energy which is stored in the flexible keel, the greater the force of propulsion. This has led to controversy when an athlete with lower limb deficiency has attempted to compete against an able-bodied athlete.

Transtibial Running Prostheses

Prior to running, it is helpful to understand the goals of the adaptive athlete. If the individual's primary desire is to jog for cardiovascular fitness, a slow jog occurs at about 140 m/min. The heel has minimal effect because the primary initial contact point is the middle portion of the foot at this speed. It may be advantageous, to use a specific running foot without a heel component, because the heel is minimally used or virtually eliminated as speeds up to approximately 180 m/min [34]. Prosthetic limb kinematics has been shown to mimic this able-bodied data [35]. The running foot is light and responsive with a significant amount of deflection on weight bearing that adds to the shock-absorbing qualities. Further weight reduction can be achieved by the adherence of running shoe tread to the plantar surface. The heel is more important if a decrease in speed occurs (e.g., jogging with intermittent walking), and a more versatile utility foot should be chosen. A sprint-specific foot should be considered if the limb-deficient athlete desires to sprint and short bursts of speed are the goal. In general, the sprint foot is designed with a much longer shank that attaches to the posterior aspect of the socket. The longer shank provides a longer lever arm for increased energy storage and return. For sprinting, the socket/limb interface should be a more intimate fitting that will maximize the transfer of motion from the limb to the socket. As with any running, use of gel liner interfaces is recommended. Choosing a thinner (3-mm-thickness) liner will reduce the motion of the tibia in the socket. For jogging, the liner should be 6 mm thickness or 9 mm thickness to maximize the shock-absorbing capabilities over a longer duration of the activity [21]. Suspension is a key factor in movement and shear reduction on the limb, and an airtight sleeve and expulsion valve can give the best limb stability [36].

Transfemoral Running Prostheses

The guidelines to design of a transfemoral running limb are similar to the transtibial running limb. The component choices are based on defining the goal of the athlete with regard to jogging and sprinting. There are not any specific differences or criteria with foot choices for either transtibial or transfemoral limbs.

The major variant in the design decision involves whether to incorporate a knee or begin with a non-articulated limb. It is a viable option to begin without a knee when stability is a concern or in individuals with limited cardiovascular endurance. Training begins with a circumducted gait to allow foot clearance in swing. If a patient intends to participate in distance running, a non-articulated system eliminates the mental concern of inadvertent knee flexion and is less demanding for a longer run.

A knee component is generally recommended when sprinting is the goal. There are several good choices available that use hydraulic control of flexion and extension resistance and that interface well with the sprint feet [21]. The overall limb alignment must be fine-tuned to the individual needs of the patient. Interlimb asymmetry has been shown to increase significantly when an athlete with transfemoral limb deficiency runs. Therefore, special attention to alignment, component adjustments, and training is particularly important [37, 38]. Maximum sports performance may require specialized components or significant deviations from standard alignment techniques to help improve interlimb symmetry and running velocity [39].

Adaptive Cycling Prostheses

Adaptive cycling is a very popular sport and recreation for limb-deficient athletes. Adaptive cycling is an excellent exercise that is non-weight bearing and indicated for individuals who may have impact restrictions or cannot tolerate higher-impact activities. There are significant variances in the adaptive cycling equipment for limb-deficient athletes given their specific level of limb deficiency which may also lead to which type of cycle they will utilize. In competitive cycling for limb-deficient athletes, the types of cycles used in competition are the bicycle, tricycle, tandem bicycle, recumbent cycle, or handcycle. Once proper fitting of the bicycle has been completed, the prosthesis will need some accommodations if more than recreational cycling is intended.

The most significant differentiation is whether the limb deficiency involves the upper or lower extremity. Athletes with upper extremity limb deficiencies usually compete with the traditional upright bicycles but may also choose to compete with recumbent or handcycles. The upper extremity limb-deficient athlete can utilize a specialty terminal device for hand breaking or upper extremity propulsion. It can either be a terminal device which can be opened and closed or can be directly clipped into the handle bars or hand crank. Other than the specialized upper extremity terminal devices, it is much less frequent for a limb-deficient athlete to utilize adaptive equipment when competing with either a recumbent or handcycle.

An athlete with lower extremity deficiency has more options in regard to the adaptive equipment. The lower extremity limb-deficient athlete may ride any type of cycle, and they may or may not ride with a prosthesis. The lower extremity limb-deficient athlete can still utilize a standard upright bicycle. Transtibial limb-deficient athletes will frequently ride with a prosthesis; however, it is possible to ride without one. Comparatively, it is more common for an athlete with transfemoral deficiency to ride without a prosthesis. When a prosthesis is utilized, it can either be a standard foot or can be a specialty terminal device attached to the socket which will clip directly into the foot pedal.

For the athlete with transtibial limb deficiency, knee flexion restriction must be minimized. Suspension systems that cross the knee, such as suction with gel sleeves, can be replaced with more advanced distal pin-and-lock options. If athlete with limb deficiency still prefers a sleeve, choose one that is pre-flexed and just tight enough to maintain an adequate suction seal. The posterior brim of the socket may be restrictive in full knee flexion and therefore is designed adequately low to allow full knee flexion during cycling yet still able to comfortably support the limb during ambulation. Otherwise, the limb-deficient athlete will need to remove his prosthesis for cycling and replaced with another for ambulation [21].

The athlete with transfemoral limb deficiency must be provided adequate clearance between the ischial tuberosity and the cycle seat. Careful adjustments to the socket in this region can usually provide comfort for limited ambulation and extended seat time. The choice of knee componentry will be based on the type of cycling that is intended. Typically, a knee that allows free motion on the bike will be easier to use. However, it is also important to choose a knee component that is safe for walking in free swing mode. The foot stiffness can be increased to ensure maximum transfer of energy to the pedal, leaving the foot excessively stiff for comfortable ambulation but more efficient for cycling. The sole of the biking shoe can be removed and attached directly to the prosthetic foot if additional weight and control are needed [21]. Unilateral transtibial limb-deficient cyclists have been shown to exhibit more pedaling asymmetry than the able-bodied population. During the time trial condition, pedaling with the flexible foot resulted in force and work asymmetries of 11.4 and 30.5%, the stiff foot displayed 11.1 and 21.7%, and the intact group displayed 4.3 and 4.2%, respectively [40].

Adaptive Golfing Prostheses

Adaptive golfing is a sport that is amenable to a wide array of impairment groups and is performed either recreationally or competitively. The longevity of potential participation in this sport may be a major factor in its popularity. Golf is a sport that can be played throughout one's lifetime. It requires good balance and truncal stability and can be played either standing or seated.

A correct golf swing requires tri-planar movements at the ankle, hip, and shoulder joints. Unfortunately, prosthetic feet cannot duplicate the three-dimensional movement of the ankle; therefore, torque absorbers or rotational adapters can be introduced. Limb-deficient golfers report that these components can help them achieve a smooth swing and follow-through and can reduce the uncomfortable rotational shear that would otherwise occur between the skin of the residual limb and the socket, leading to improved hip and shoulder rotations, particularly in the left-sided limb-deficient athlete [41, 42].

There are different specialty adaptive devices available to the athlete with limb deficiency of either the upper or lower extremity. Additionally the athlete may opt to participate without any adaptive equipment, particularly in an upper extremity athlete who may utilize only one arm for the golf swing. The upper extremity limb-deficient athlete who chooses to golf utilizing a prosthetic device would incorporate a specialty terminal device to assist with maintaining a proper grip on the golf club. Athletes with lower extremity limb deficiency may play with a traditional lower extremity prosthesis, or they can utilize a specialty prosthesis. Specific modifications to the lower extremity prosthesis for golfing may utilize a torsion adapter to allow more motion and reduce stress on the residual limb and prosthetic components. Additional options include adding a rotational component to the shank or a swivel component to the ankle.

Winter Sports Adaptive Equipment

Adaptive Alpine (Downhill) Skiing Equipment

The person with limb deficiency interested in winter sports currently has an unprecedented opportunity for participation. There are numerous options for adaptive skiing equipment for the limb-deficient athlete. Individuals with limb deficiency can ski recreationally or in competition. There are a variety of options for adaptive sports equipment in alpine skiing for persons with limb deficiency. The adaptive equipment will vary as the limb-deficient athlete can opt to either ski standing or seated. Additionally, the equipment varies based on whether they have upper or lower extremity limb deficiency.

Upper extremity amputees will typically ski standing and may opt for no additional adaptive equipment. However, if they opt for additional equipment, it would be either a prosthesis with a hand to hold a ski pole or a specialty terminal device with the ski pole attached at the end. An outrigger is a modified forearm crutch (Lofstrand), attached to ski tips. These ski tips may be attached in a fixed position or can have a special release to allow them to alter between a flat and pointed position and is then known as a "flip-ski." For the individual with a deficient lower extremity interested in alpine skiing, there are multiple prosthetic options that vary between persons with transtibial and transfemoral limb deficiencies. The skier with lower extremity deficiency can either ski standing or seated. However, sit skiing is typically only pursued in persons with bilateral lower extremity limb deficiencies and most commonly at the transfemoral level. The skier with a single lower extremity deficiency may opt to ski standing with or without a prosthesis. Unilateral transfemoral limb-deficient skiers will usually opt to use a single ski with bilateral outriggers.

Many skiers with unilateral lower limb deficiency, particularly at the transtibial level, continue to use a prosthesis. When a person with lower extremity limb deficiency opts for a skiing prosthesis for recreational skiing, it is important for the physician to be aware of how these prostheses should be prescribed. Although a walking limb can be adapted and used, a ski-specific alignment should be performed for the duration of the activity. The major differences between the skiing prosthesis for the person with a transfemoral and transtibial deficiency are the socket and the addition of a knee unit. Many knees can be utilized but typically would initially utilize a single axis knee, and some advanced skiers may consider more dynamic options as their skill level progresses. The center of gravity for the prosthesis should be set in front of the ankle. The anterior socket brim should be 1 in. behind the prosthetic toe, and the prosthesis length should be reduced to create a flexed lower limb in an athletic stance. Additional foot dorsiflexion and external knee support should be added. For advanced users, specialty feet that eliminate the boot are available. The plantar surface of the ski foot is modeled after the boot sole and can be attached directly to the ski bindings, thus eliminating the boot altogether. This eliminates excess weight but, more importantly, enhances energy transfer to the sporting equipment for more efficient performance. Another option is to utilize a traditional foot as the terminal device, so the limb-deficient athlete can doff the ski and continue to ambulate normally with their prosthesis inserted into a ski boot. The foot can vary from a solid ankle cushioned heel (SACH) foot to dynamic-response feet. However, when placing the prosthetic foot into the ski boot, a 1 in. heel wedge should be placed under the heel to provide a forward cant.

Adaptive Nordic (Cross-Country) Skiing Equipment

Nordic skiing, also referred to as cross-country skiing, is skiing over a groomed or natural terrain using upper/lower extremities synchronized in a striding and gliding motion that creates a full-body aerobic workout. Adaptive equipment for the sport is tailored to those who can stand and ski and those who sit ski. Equipment can be modified to accommodate nearly any ability or injury. The limb-deficient athlete can participate with or without a prosthesis and be seated or standing.

In classic standing Nordic skiing, the athlete skis in or out of a groomed track with the skis and arms moving in a parallel motion fore and aft with arms and legs moving diagonally with respect to each other (similar to walking or jogging). As a stand-up adaptive Nordic skier progresses, the initial shuffling motion becomes more fluid and transitions to a kick and glide motion. The skier remains in an athletic stance, balanced over the center of the ski. When approaching an uphill grade, the skier moves the center of gravity slightly back onto the heels of the ski, allowing the ski to grip the snow. When approaching a downhill, the skier moves over the center of the ski, bends a little at the waist, and pushes the tails in to a wedge shape, creating more friction and slowing the skier down.

There are a variety of options for a prosthesis. Given the nature of Nordic skiing, the focus on the prosthesis is for endurance and typically has a lighter weight design. The prosthesis will incorporate a torsional component to assist with the standard skiing technique of this sport.

Standard equipment consists of skis, boots, and poles. These skis are longer and narrower than alpine skis, which creates less drag and makes the ski easier to propel. The length of the ski is determined by the skier's height, weight, and skiing ability. Generally, a shorter ski is easier to control, while a longer ski adds stability and glides farther. Pole length for the classic technique should be between the axilla and top of the shoulder and between the chin and mouth for the skate skiing technique.

The adaptive equipment for seated Nordic skiing varies significantly compared to the sit ski utilized in alpine skiing. Typically the frames will sit lower to the ground and will be lightweight. Similar to the alpine sit ski, there is a seating system attached to the frame. The sit ski may utilize additional suspension given the terrain; however, many will not add the extra weight of suspension given that the typical terrain is relatively flat. The Nordic sit ski typically utilizes a shorter frame for more turning power. The skis used for are similar to those used when standing.

Adaptive Snowboarding Prostheses

There is a limited amount of adaptive equipment that has been developed specifically for snowboarding. Until recently, para-snowboarding has not been a competitive sport and was only performed recreationally. However, the sport has evolved thanks to popular extreme sport events such as the Winter X Games and for the first time was included in the Paralympics at the 2014 Winter Games in Sochi, Russia.

At present, the only configuration has the terminal device attached directly to the snowboard, and the terminal device can be directly attached to the distal socket by a quick release coupler. This allows the limb-deficient athlete to utilize their traditional prosthesis, detach the walking terminal device, and attach the snowboard and specialty terminal device once the athlete reaches the slopes.

Snowboarding has been performed by in persons with bilaterally transfemoral limb deficiency. The feat has been achieved through the development of prosthetic knee components with shocks and by directly attaching the prosthesis to the board. The immense popularity of snowboarding has accelerated developmental designs for the transfemoral limb-deficient athlete. A recently released knee has been designed specifically for sports that require a loaded, flexed knee position. This design utilizes a Bartlett Tendon which is a specialized shock absorber which aids in knee extension and utilizes the weight load and unloading to assist with knee flexion and extension. Snowboarders are in bilateral dynamic hip, knee, and ankle dorsiflexion as they negotiate the hill. This knee is adjustable and produces the weighted knee flexion necessary to snowboard successfully. The transtibial snowboarder needs additional ankle dorsiflexion range and flexibility in the prosthetic foot.

Water Sports

Water sports are also a popular activity for limb-deficient individuals. Depending on geographical location, water sports may be part of the culture. Most prostheses will tolerate occasional, minimal moisture exposure, particularly when protected under a layer of clothing. As with any everyday prosthesis, the prosthesis should be resistant to splashes that occasionally occur, especially when living in a wet climate. A specialized, waterproof design is necessary when the athlete with limb deficiency will have regular exposure to water, especially if complete immersion is intended. For the bilateral transfemoral-deficient swimmer, prosthetic devices are usually bypassed in favor of specialty seating systems that allow participation at the highest levels [37].

Adaptive Swimming Prostheses

A person with limb deficiency can choose to train with or without a prostheses; however, no prostheses are worn during competition. There are certain advantages for the limb-deficient athlete to utilize a swimming prosthesis such as exercising the residual limb musculature, increased stability when diving, climbing on the ladder to exit the pool, and to protect against injury. A limb-deficient athlete who would prefer to use a prosthesis for swimming has several options. The most simplified adaptive prosthesis would be to attach a specialty terminal swimming fin directly to the socket. However, there are more specialized prostheses which can be made for the athlete. For the transfemoral limb-deficient athlete, there are knee devices which are beneficial for swimming. The locking knee allows the knee joint to bend for walking around the pool or at the beach and then can lock in extension to put the leg in a straight position for use in the water. The buoyancy of the prosthesis will allow the distal leg to float. Another knee option is the Aulie Nylon Knee, which was designed specifically for water use. It utilizes a locking pin system and is available with or without hydraulic control. There are also several swimming ankle options to choose from. The benefits of a swimming ankle are that it can be adjusted to accommodate both swimming and walking. The swimming ankle will allow the swimmer to lock the foot into a pointed position for swimming to simulate the natural position of the foot when swimming but then can be locked in a neutral position for walking. Specific examples of the various swimming ankles are the Ortholite Leisure ankle which utilizes a lever to enable the athlete with lower limb deficiency to change the foot from a walking to a swimming position versus the Activankle and Swimankle which also enable the athlete with lower limb deficiency to change the foot position from walking to swimming.

Adaptive Kayaking Prostheses

Kayaking requires stabilization of the legs inside the boat to assist with turning and most importantly to assist in righting the kayak if it capsizes. Traditional prosthetic feet are difficult to fit in and out of the kayak and can slip easily off of the foot pegs. A monolithic design connects the prosthesis to the foot peg using a bungee cord allowing multiaxial movement and can facilitate quick exit out of the kayak.

Adaptive Rock Climbing Prostheses

Rock climbing has been increasing in popularity in the recent years. No longer does one have to travel to the natural outdoors to enjoy the exhilaration of this experience. Local indoor and outdoor climbing systems are available in many locations.

As with all the other sports covered in this article, rock climbing can be either a recreational activity or a competitive sport. There are several adaptive modifications that be made for the individual with limb deficiency whose chooses to pursue this recreational activity. Climbers with upper extremity deficiencies need to use a prosthesis with an alternative cable system, as the typical motions which provide tension to open and close standard terminal devices could cause the climber to fall from the climbing wall or cliff. There also needs to be a robust design for the suspension of the prosthetic socket which mainly utilizes a vacuum suspension to prevent the socket from detaching while the athlete with limb deficiency is climbing. Another option is to incorporate a specialized terminal pick that would attach directly into the socket and is designed for either rock or ice climbing.

An adaptive prosthetic modification for the athlete with a lower limb deficiency incorporates a specialty terminal device with rock climbing feet. The specialty rock climbing feet will allow better purchase on the wall and can be designed with the ability to adjust the length of the prosthesis for different climbs. Commercially produced prosthetic feet are typically unsuitable for rock climbing. The toe must be rigid enough to support the full-body weight when only that portion of the prosthesis is in contact with the rock face. The foot should be shortened to decrease the torque and rotation found with a longer lever arm. The shape of the foot should be contoured to take advantage of small cracks, crevices, and contours of the climbing surface. Once an acceptable shape has been obtained, completely covering the foot with the soling from climbing shoes will give the texture needed for optimum grip. Making the prosthesis easily height adjustable allows the user to optimize limb length for different types of climbs. A quick disconnect coupler facilitates changing quickly back into feet designed for hiking. If no prosthesis is used, limb protection should be provided.

Hiking Prostheses

Hiking can be performed with either a everyday prosthesis; however, more advance terrain may require a specialty prosthesis. Hiking on uneven terrain requires consideration of a multiaxial ankle, allowing the prosthetic foot to conform to irregular surfaces, thus reducing the forces transferred to the residual limb.

As the limb-deficient individual enters midstance on the prosthesis, the foot should accommodate uneven terrain and help control advancement of the tibia. If tibial advancement is too abrupt, the athlete with lower extremity deficiency will resist this knee flexion moment, increasing the forces on the residual limb within the socket. When aligning and adjusting a new prosthesis, the athlete with lower extremity deficiency should be evaluated on surfaces similar to those that will be encountered in the athletic activity.

Perhaps even more significant than multiaxial feet and torque absorbers is a motorized ankle. This type of ankle senses electronically when the user is on an incline or decline rather than generate propulsive power. The ankle requires two strides to sense the orientation, and then it will consequently plantar flex or dorsiflexed the foot to ease the moments that are induced on the knee and the forces that act on the residual limb [21].

Energy Cost of Ambulation

Amputation of a lower extremity significantly affects the energy cost of ambulation. There are various measurements that have been utilized to quantify the "cost" of ambulation in persons with limb loss, and these calculations can be expressed in functions of distance, rate, and velocity. Persons with limb loss typically will walk slower than non-amputees to maintain a similar oxygen consumption rate. Therefore, in athletic competition the amputee athlete will need to increase their rate of oxygen consumption in order to maintain a similar velocity of a non-amputee athlete. When comparing ambulation of amputees to non-amputees, the rate of oxygen consumptions per unit distance is increased in the limb-deficient population [43–45]. This information should be of particular interest in the future discussions of the competition of amputee athletes versus non-amputee athletes. There are not any current studies in the literature comparing the energy cost of ambulation of an individual born with congenital limb deficiency with an able-bodied person.

Controversies

Advances in rehabilitation medicine and adaptive technology in the development of prosthetic devices have led to some controversy in competition against other athletes with disability. Access to different types of technology and materials can differ greatly depending on the athlete's socioeconomic status and country of origin, creating the potential for significant competitive imbalance between similarly disabled and conditioned athletes.

These advances have also been cause for controversy in competition against able-bodied athletes, with continued improvements in prosthesis weight and energy storage capabilities being a potential source of a competitive imbalance. The topic of the comparative kinetic energy in the flexible keel to the human leg is controversial. There is specific concern as to the length of the prosthetic limbs and subsequently the amount of energy stored in the keel. Typically the longer, more linear flexible keels will store the most energy. The more energy which is stored in the flexible keel, the greater the force of propulsion. This has led to controversy when a lower extremity limb-deficient athlete has attempted to compete against an able-bodied athlete.

However, many of these comparisons do not take into effect the increased energy cost of ambulation for the limb-deficient athlete. Therefore to fully assess the energy-storing advantages in the prosthetic limb, the investigator needs to also be cognizant of the additional energy for the limb-deficient athlete needs to utilize to ambulate with the prosthetic device. Determining the most appropriate methods for assessment and rectifying any potential competitive imbalance in either case will likely be an area of considerable evolution in the near future.

Conclusion

When generating a prosthetic prescription, physicians and prosthetists should consider the needs and preferences of the athlete with limb deficiency, as well as the functional demands of the sports activity. Physical training status should be evaluated before intensive participation, particularly in sports unfamiliar to the participant. As an individual begins sports participation, a standard prosthesis can be used or partially adapted so that it functions adequately for the sport. As the athlete with limb deficiency progresses and the demands of participation increase, a specialized prosthesis can be provided. A properly designed prosthesis can substantially expand the opportunities for participation in sports and augment the overall goals of the rehabilitation plan for each patient.

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Part II

Medical Considerations in Adaptive Sports Medicine

Review of Injury Epidemiology in Paralympic Sports

4

Lauren Rudolph and Stuart E. Willick

Introduction

Evolution of Paralympic Sports

Few sporting events have seen such a rapid pace of change as the Paralympics. There has been an exponential increase in participation starting from 16 individuals with spinal cord injury competing in the first Stoke Mandeville Games, which took place on the opening day of the 1948 London Olympic Games. Fast forward to the more than 4000 athletes that took part in the London 2012 Paralympic Games with packed audiences and worldwide coverage. The increase in participation has paralleled the addition of many new sports (Table 4.1), changes in the amount of individual participation, advancements in technology, and inclusion of additional impairment types. Understanding the rapid evolution of Paralympic sport helps one to comprehend the variability in literature concerning the risks of participation in the Paralympics.

In 1976 the Paralympic Games allowed participation of athletes with visual impairment and athletes with limb deficiency for the first time. Held in Toronto, these Games were known as the

Table 4.1 Comparison of sports included in 1960 vs. 2016–2018

9th Annual International Stoke Mandeville Games (1960, Rome)	Paralympic sports planned for 2016–2018
Archery Athletics Dartchery Snooker Swimming Table tennis Wheelchair basketball Wheelchair fencing	*Winter:* IPC Alpine Skiing IPC Biathlon IPC Cross-Country Skiing IPC Ice Sledge Hockey Wheelchair curling *Summer:* Archery IPC Athletics Badminton Boccia Canoe Cycling Equestrian Football 5-a-side Football 7-a-side Goalball Judo IPC Powerlifting Rowing Sailing IPC Shooting Sitting volleyball IPC Swimming Table tennis Taekwondo Triathlon Wheelchair basketball IPC Wheelchair Dance Wheelchair fencing Wheelchair rugby Wheelchair tennis

L. Rudolph, MD • S.E. Willick, MD (✉)
Division of Physical Medicine and Rehabilitation, University of Utah, 590 Wakara Way, Salt Lake City, UT 84108, USA
e-mail: Stuart.Willick@hsc.utah.edu

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_4

Olympiad for the Physically Disabled. In 1980 athletes with cerebral palsy and athletes with physical disabilities not fitting into the previously defined categories (Les Autres, French for "the others") were also included in the Games, at that time called The Arnhem Summer Olympics for the Disabled. Although athletes with intellectual disabilities have participated in some Paralympic Games in the past, injuries in this athletic population will not be a focus of this chapter.

Changes in amount of individual participation impose a further complication for interpreting the available data. In the 1970s and 1980s, it was not uncommon for an individual athlete to compete in multiple sports at the Paralympic Games. For example, a survey of 128 athletes, published in 1985, found 79% of these athletes were competing in track events, 71% in wheelchair basketball, 57% in road racing, and 60% in field events [1]. Although it was commonplace initially, this occurrence is rare in elite adaptive sports today.

Advancements in technology have also changed performance parameters and injury risk characteristics during the past two decades. Designs for wheelchairs and prostheses are quickly evolving. Lightweight, high tensile strength materials continue to improve. In addition, training protocols and access to specialized trainers, coaches, and medical personnel have progressed in the last 20 years. Subsequently, comparisons between injury patterns seen 10–20 years ago with those seen currently may not be appropriate and findings from older research articles in this area may not reflect the current environment in elite Paralympic sport.

Definition of Injury

The interpretation of study results is additionally challenging with a lack of consensus on what constitutes an injury and when it should be reported. The definitions of injuries reported vary between studies. Without fail, the definition of injury influences both the data collected and the risk assessment of the sports studied. For instance, several retrospective questionnaire studies included minor soft tissue injuries, listed as blisters or abrasions, for which no medical attention was sought. However, other research efforts, which were based on the organizing committee's medical services at the Paralympic Games, did not include such minor soft tissue injuries.

Review of the Literature

The aim of this chapter is to review the current literature on adaptive sports epidemiology, ultimately in a quest to provide the best care for Paralympic athletes. Source material for this review were primarily published articles and reports from a literature search of PubMed and SPORTDiscus. Information was also collected and evaluated from Congressional proceedings as well as both published and unpublished articles known to the authors but not identified through these database sources. Articles published in English were used primarily, but some German texts were incorporated when translation was available. Search terms involved permutations and combinations of Paralympic, sport, disability, injury, cerebral palsy, visually impaired, and wheelchair.

The unique grouping of sports by disability in Paralympic sport is complex and makes obtaining a clear picture of injury risk difficult. There are currently 30 Paralympic sports (Table 4.1) which include 25 summer events planned for Rio 2016 and five winter events planned for PyeongChang 2018. Some sporting events such as Athletics allow participation by athletes with different impairments, including athletes with spinal cord injury, visual impairment, limb deficiency, and cerebral palsy. Other sporting events are unique to a particular disability category. For example, goalball only allows competition by athletes with visual impairment, whereas wheelchair rugby has sole participation by athletes with impairment in all four limbs. Clearly this makes investigating the risk of injury related to a particular sport for the upcoming 2016–2018 Games quite challenging. Further, some sports are modified by equipment specific to impairment such as a sledge for ice hockey. Comparatively, alpine skiing features multiple events (downhill, super-G, super combined, giant slalom, slalom, and snowboard), and its participants have options between multiple types of equipment (single ski, sit ski, or orthopedic aids) adapted to the athlete's impairment. Some sporting events such as basketball require multiple classes of disability to be included on the same team.

Caution is also required when interpreting studies where the investigation is focused on the risks related to a particular class of disability across different sports. For example, an athlete with a lower limb deficiency may compete with a prosthesis for track athletics or cycling, without a prosthesis for swimming or high jump, or in a wheelchair for sports such as basketball and tennis. Athletes with cerebral palsy may be ambulant or wheelchair users depending upon their degree of impairment. Some more recent studies have used a combination of impairment and sport specificity to limit these confounders but so far have relatively few athlete numbers [2–4].

In order to review the literature and better understand possible patterns of injury, this chapter is broken down into three categories: location, type, and rate of injury. For the location of injury, we attempt to identify common anatomic locations prone to injury. In the type of injury, we discuss both the etiology and medical diagnosis of injury and acute versus chronic injury patterns. Whereas for the rate of injury, we review injury incidence rates divided by winter and summer sports.

Anatomic Location of Injury

Winter Sports

Lower limb injuries are frequent in winter sports such as alpine skiing and ice sledge hockey. However, through the research efforts of the International Paralympic Committee, certain ice sledge hockey injuries have become less common following regulation changes on protective equipment and sledge height. Specifically, Webborn et al. [5] reported four lower limb fractures occurring in spinal cord-injured ice sledge hockey athletes during the 2002 Winter Games. After rule changes were made to improve protection, only one lower limb fracture occurred in ice sledge hockey over both the 2006 and the 2010 Winter Games combined. Interestingly, athletes in seated alpine ski racing classes consistently had more upper limb injuries than lower limb injuries in the 2002, 2006, and 2010 Winter Paralympic Games [5–7]. Injuries to the head and neck in both ice sledge hockey and alpine events were also common.

Summer Sports

Upper limb injuries are common among wheelchair athletes and Paralympians participating in the Summer Games. The upper limb, particularly the shoulder, is the most common site of injury in studies involving athletes who compete in wheelchairs. The prevalence of shoulder injury ranges from 19% [8] across multiple wheelchair sports to 72% in female wheelchair basketball players [9]. However, Webborn and Turner [10] noted in their report on 244 British athletes seen during a 4-week period, including the buildup to and the competition in a Summer Paralympic Games, that although the shoulder was the most common site of subjective pain in wheelchair athletes (30%), the spine was more often the actual objective site of pathology. Specifically, the cervical spine (59%) and thoracic spine (8%) were identified as the cause of shoulder pain in wheelchair athletes who presented with a chief complaint of shoulder pain, while in 33% of these athletes the shoulder was the actual site of pathology. Irrespective of impairment type and adaptive technology used, the distribution of injury by body part was greatest in the upper limb (50.2% of all injuries) during the 2012 London Summer Games [11] with shoulder injuries being most prominently reported location of injury (17.7% of all injuries).

Although common, an upper limb injury was not the most common injury in all sports and disability groups. When looking at a more specific athlete population, such as standing volleyball players with an impairment, shoulder injury was not the most common location of injury, thus showing variation by individual sport. Reeser [12] identified the foot and ankle as the most common site of injury (21%), followed by the shoulder (18%), wrist and hand (18%), and the knee (14%) in a report of injury patterns among elite disabled standing volleyball players, which involves athletes with upper and lower limb impairments including amputation. In this study, the distribution of injury locations was not related to the specific type of disability. Similarly in a 4-year study examining injury in thirteen Brazilian footballers with visual impairment [2], the greatest proportion of injuries reported were lower limb (80%), head (8.6%), spine (5.7%), and upper limb injuries (5.7%).

Type of Injury

Acute vs. Chronic

Table 4.2 shows the percent distribution of acute and chronic injuries reported in the literature for most winter and summer Paralympic sports with acute injuries being slightly more prevalent [1–7, 11–20]. Over all sports studied, there is a 55:45 mean ratio of acute to chronic injuries. However, there is marked variation by sport, understandably with differences seen between contact and endurance sports. Most of the injuries recorded in the injury registry for the 2002

Table 4.2 Distribution of injury onset: acute vs. chronic

Study	Impairments included	Type of sport	Sample	Injuries	Acute/chronic (%)
Winter sports					
Ferrara et al. [20]	SC, A, LA	Alpine skiing	68	68	50:50
Webborn et al. [5]	SC, A, CP, LA, VI	Alpine skiing	194	24	91:9
		Ice sledge hockey	134	12	83:17
		Nordic skiing	88	3	50:50
Webborn [6]	SC, A, CP, LA, VI	Alpine skiing	190	23	78:22
		Ice sledge hockey	112	12	64:36
		Nordic skiing	132	5	80:20
Webborn et al. [7]	SC, A, CP, LA, VI	Ice sledge hockey	118	40	40:60
Summer sports					
Curtis and Dillon [1]	SC, A, CP, LA	Wheelchair sports	1200	128	40:60
Ferrara and Davis [13]	SC	Wheelchair sports	19	19	65:35
Burnham et al. [14]	SC, A, CP, LA, VI	Summer Paralympic	151	108	49:51
Richter et al. [15]	CP	Summer Paralympic	75	27	73:27
Ferrara et al. [16]	SC, A, CP, LA, VI	Summer Paralympic	426	137	46:54
Taylor and Williams [17]	SC	Wheelchair racing	53	38	41:59
Reeser [12]	A, LA	Standing volleyball	89	41	60:40
Ferrara et al. [18]	SC, A, CP, LA, VI	Multisport	1360	1037	77:23
Nyland et al. [19]	SC, A, CP, LA	Summer Paralympic	304	254	67:33
Magno e Silva et al. [2]	VI	Football 5-a-side	13	35	80:20
Magno e Silva et al. [3]	VI	Swimming	28	41	20:80
Magno e Silva et al. [4]	VI	Track and field athletics	40	77	18:82
Willick et al. [11]	SC, A, CP, LA, VI	Summer Paralympic	3565	633	68:32

SC spinal cord-related impairment, *A* amputee, *CP* cerebral palsy, *LA* Les Autres, *VI* visually impaired

Winter Games were of acute, traumatic onset and involved the disciplines of alpine skiing and ice sledge hockey [5]. This variation by sport may, in part, be a function of when the injury data were collected with competition surveys reporting more acute injuries [12, 19, 21] and longitudinal surveys reporting more chronic injuries [1, 16].

Diagnosis

The most common diagnoses represented in the 2002 Winter Games [5] were sprains (32%), fractures (21%), strains (14%), and lacerations (14%). In winter Paralympic sports, contusions, fractures, and concussion are more prevalent than in Summer Games likely because of the impact potential and high speeds obtained during play. For example, in the 2002 Ice Sledge Hockey Games, fractures comprised 33% of injuries, and after modifications in regulations on protective equipment and sledge height, fractures accounted for 7.5% of all sledge hockey injuries in 2010. In Nordic and alpine skiing, there were four head injuries in the 2010 Winter Games, three of which prevented further participation in competition.

In summer Paralympic sports, strains (mean = 25%; range, 4–60%) and sprains (mean = 22.8%; range, 3.7–48%) were reported to be the most common injury types by the authors of a previous review published in 2009 [22]. However, self-report data was used in the majority of these studies, which has inherent limitations. In addition, the percent of strains and sprains reported varied greatly between studies. Three longitudinal studies [2–4] of visually impaired athletes competing in swimming, football 5-a-side, and athletics (track and field) reported injuries during a 5-year period in one national team squad. Two of the studies describe "muscle spasms" as the most common injury type but without further explanation as to whether this definition indicates muscle cramp, neurally mediated spasm, or was fatigue related. Thus, the true etiology and its significance for injury prevention remain unclear.

Rate of Injury

A comparison of injury rates (IRs) for both winter and summer sports has been reported in prospective and retrospective research and is summarized in Table 4.2. Some of these studies include multiple impairment groups whereas other studies cover only a single impairment group, and some studies report on individual sports whereas other studies survey multiple sports. Regardless, IRs show variation by individual sport within both Winter and Summer Games.

Winter Sports

The injury risk reported during the 2010 Vancouver Winter Paralympic Games was significantly greater than that recorded during the 2002 and 2006 Winter Paralympic Games. Injuries were reported in 24% of all athletes participating in the 2010 Winter Games [7] as compared to 9.4% in the 2002 Winter Games and 8.4% in the 2006 Winter Games [6]. This may reflect improved injury surveillance methodology and data capture. Alternatively, the increased number of injuries reported during the 2010 Winter Games may have been due to the inclusion of athletes who presented to the polyclinic for sports massage, which generated a diagnosis of "muscle pain" in the injury database. The 2010 Vancouver study [7] also highlights the high risk of injury in the sports of alpine skiing and ice sledge hockey in particular as well as an increased injury risk in 2010. There were a total of 120 injuries among the 505 athletes at the Vancouver Winter Games (incidence proportion 24%, 95% CI 20.1–27.7). In alpine skiing, 22% of these competitors presented with an injury as compared with 13% in 2002 and 12% in 2006. For ice sledge hockey, 34% of competitors presented with injury in 2010, compared with 14% in 2002 and 11% in 2006. Although the injury data from the Sochi 2014 Winter Paralympic Games has not yet been published at the time of this writing, the researchers noted exceedingly high injury rates in alpine skiing as well, possibly due to poor course conditions created by warm temperatures (personal communication).

For comparison, Nordic skiing (18.6%) and wheelchair curling (18%) had lower injury rates in 2010. IRs in wheelchair curling were consistently low across the two Winter Games in which the sport was included (2006 and 2010). In fact, there were no recorded injuries in 2006. In 2010, although nine of 50 curlers sought medical attention, none of these were acute injuries, and five of the nine encounters were for non-sport-related symptoms that started prior to the Games. Similar to able-bodied athletes, it is likely that athletes with impairments are more prone to injury at higher levels of competition and that alpine skiing at the recreational level carries less risk of injury. For example, a multicenter study published in 1985 describing injuries occurring in disabled recreational alpine skiers reported an injury incidence of only two injuries per 1000 skier days [23].

Summer Sports

The first study to attempt to quantify exposure data was a 2-year prospective study of 319 athletes with various impairments competing in summer Paralympic sports [16]. Ferrara et al. reported an overall IR of 9.3 injuries per 1000 participation hours. Unfortunately no sport-specific details were provided and self-reported symptoms were used. The robust and comprehensive London 2012 study reported an overall injury incidence rate of 12.7 injuries per 1000 athlete days (95% CI 11.7–13.7). The overall injury incidence proportion was 17.8 injuries per 100 athletes (95% CI 16.5–19.0). There were marked variations by sport with the greatest injury rates in football 5-a-side, goalball, powerlifting, wheelchair fencing, and wheelchair rugby with IRs of 22.4, 19.5, 19.3, 18.0, and 16.3 (injuries/1000 athlete days), respectively. Sports with the lowest IRs were sailing, rowing, and shooting (4.1, 3.9, and 2.2 injuries/1000 athlete days, respectively).

A separate study describing Polish athletes also reported on the 2012 London Summer Games, as well as the 2008 games in Beijing [24]. Gawronski et al. found an incidence rate of 29.8 per 1000 athlete days (95% CI 22.1–37.6) in 91 Polish Paralympians at the 2008 Summer Games. However they found an incidence rate of only 15 per 1000 athlete days (95% CI 9.0–21.0) in 100 Polish athletes at the 2012 Summer Games, suggesting that IRs decreased from the 2008 to 2012 Summer Games. Three studies examining injury in elite Brazilian visually impaired athletes recorded longitudinal data during the period of 2004–2008 in three separate sports. However, sample size was small and limited to one nation [2, 4]. Allen [25] reported an injury prevalence of 6.3% in a survey of sailors with various impairment types at the International Foundation for Disabled Sailing World Championship (*n* = 24 teams). McCormick and Reid [8] reported the prevalence of injury in basketball (30.9%), athletics (30.6%), and road racing (12.1%) in a retrospective survey of wheelchair athletes. However, blisters and abrasions formed approximately 50% of these injuries, many of which did not require formal medical treatment.

Discussion

A variety of methodological limitations were evident in the literature, which confounds comparisons across studies. This was particularly prominent in earlier studies. Limiting factors included a lack of standard definitions for reportable injury and injury details, short study time frames, poor or absent exposure data, use of self-report surveys that did not include a confirmed medical diagnosis, small sample sizes, and the unique grouping of sports by disability. Most early studies lacked exposure data and were therefore unable to calculate incidence rates. The studies that use self-reported data raise questions about the validity of injury diagnoses in these works. Physician or therapist diagnosis was the basis for diagnoses in studies by Burnham et al. [14] and Webborn et al. [5] and thus are more applicable to clinical practice.

In addition to a variety of limitations in the literature, there has been a rapid evolution in Paralympic sports with changes in technology and increased participation. Ultimately a broad overview of injury patterns in Paralympians loses sight of risk factor relationships for specific sporting events and impairment types. Conversely, the small sample size of a particular combination of sport plus impairment type tends to lack statistical power making it more difficult to apply data in clinical practice. In an attempt to address some of these issues, the International Paralympic Committee implemented an Injury Surveillance System, which started with the 2002 Salt Lake City Winter Paralympic Games and continued at all subsequent Winter Games. The first summer injury and illness survey was implemented during the London 2012 Summer Paralympic Games.

Historically, data was lacking but several more recent studies have made significant strides toward helping to better establish injury patterns. The largest and most comprehensive epidemiological report examining injuries in Paralympic athletes to date is the injury and illness survey conducted around the London 2012 Summer Games [11]. Willick et al. captured data from 3565 athletes (84% compliance by athletes) from 160 delegations (98% compliance by delegation) during training and competition in the 20 summer sports. A total of 49,910 athlete days were monitored during which a total of 633 injuries in 539 athletes were documented. This was the first study to capture exposure data for all athletes at the Paralympic Games.

Conclusions

The literature examining injuries in athletes with physical impairments during the past two decades contains significant variability with regard to injury definitions, research designs, data collection methodology, and analytic approaches. However, patterns of injury are emerging with assistance from injury surveillance studies. Injury rates and anatomical location of injury differ according to sport and impairment. These findings highlight the need for longitudinal event-specific, sport-specific, and impairment-specific studies. Ultimately, to inform injury prevention strategies in the Paralympic athlete population, it is imperative that the International Paralympic Committee continue the Injury Surveillance System while also encouraging and supporting longitudinal sport-specific studies.

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5 Medical Considerations in Adaptive Sports

Anthony Beutler and Patrick Carey

All athletes, including adaptive athletes, may have medical conditions and injuries that impact their ability to participate in sports. However, injuries and illnesses for an adaptive athlete can pose a unique and complex challenge for physicians. To provide quality care during competition and training, physicians should be familiar with common medical conditions in athletes in each of the six disability categories: wheelchair athletes, athletes with amputations, athletes with cerebral palsy, visually impaired athletes, athletes with intellectual impairment, and athletes classified as les autres [1].

Pre-participation Physical Examination

A thorough pre-participation evaluation (PPE) is critical to determining the health status of any athlete. The PPE screens for injuries or medical conditions that may place an athlete at risk of further injury [2]. In contrast to the 1–3% incidence of sport-significant abnormalities found in able-bodied athletes, in Special Olympians the incidence is closer to 40% [3]. The standard recommendation is that the evaluation be performed at least 6 weeks in advance of competition to allow adequate opportunity for any identified health concerns to be addressed, and lead time is particularly critical in athletes with disabilities where complex equipment and widely diverse medical issues are more likely to be present. In addition to the standard aspects of the PPE for able-bodied athletes, there are additional considerations for the sports medicine physician when evaluating adaptive athletes. The current PPE monograph endorsed by the American Academy of Family Physicians, American Academy of Pediatrics, American College of Sports Medicine, American Medical Society for Sports Medicine, American Orthopaedic Society for Sports Medicine, and American Osteopathic Academy of Sports Medicine includes a supplemental history form for the adaptive athlete in addition to the recommended history and physical examination form for able-bodied athletes [4]. A similar PPE monograph recently proposed by a team of sports medicine specialists in Canada is based on the International Olympic Committee consensus statement and includes a more comprehensive format for the adaptive athlete. Some of these additional recommendations include assessment of functional daily activities and evaluation of orthoses and other adaptive devices [2]. Current recommendations are that a

A. Beutler, MD
Professor, Uniformed Services University, Department of Family Medicine, Bethesda, Maryland, USA
e-mail: anthony.beutler@usuhs.edu

P. Carey, DO (✉)
US Army, Fort Benning, Columbus, GA 31904, USA
e-mail: patrickca@pcom.edu

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_5

PPE be performed upon entry into sports and should be repeated at least every 2–3 years, depending on the age and participation issues of the athlete. An interim evaluation (often just a brief history and blood pressure) prior to each sport season may be necessary to determine if the athlete's health condition has changed [5].

The medical team involved in the longitudinal care of the adaptive athlete should perform the PPE, since as knowledge of baseline functioning is critical to proper recommendations and protections for the athlete. Physicians should complete the PPE in a systematic and comprehensive fashion and should avoid the common mistake of becoming overly focused on the athlete's impairment/disability and overlooking other medical and pre-participation issues. The evaluation of an adaptive athlete often requires a multispecialty team approach. For example, a physician specializing in sports medicine and a spinal cord injury specialist may work together to jointly assess an individual with spinal cord injury (SCI) and safely clear them for participation.

The sport, level of participation, athletic organization, clinical indications, and medical conditions of the athlete determine the required elements of the PPE. The PPE should provide information to guide the athletic organizer, athlete, trainer, coach, and team physician toward safe participation for the athlete [5].

The PPE should achieve the following objectives [5]:

- Identify conditions that require further evaluation before training, require close supervision during training, or may predispose them to injury
- Determine the athlete's general health and fitness level
- Counsel the athlete on health-related issues and methods for safe participation

Cardiovascular and pulmonary evaluations seek to identify conditions that may lead to disease progression or sudden cardiopulmonary collapse. Suggested guidelines for cardiovascular screening of the athlete are available from the 36th Bethesda Conference: *Eligibility Recommendations for Competitive Athletes With Cardiovascular Abnormalities* [4, 6].

Additional elements of the PPE for adaptive athletes should include an assessment of predisability health, present level of training, current medications and supplements used, presence of impairments, level of functional independence for mobility and self-care, history of prior sports participation, and anticipated needs for adaptive equipment. Assessment of sensory deficits, neurologic impairment, and joint stability, range of motion (ROM), muscle strength, and skin integrity are even more important in the population of adaptive athletes compared to able-bodied athletes. An evaluation of the athlete-equipment interface is critical to a proper PPE. For instance, during the musculoskeletal examination of an athlete who uses a wheelchair, the physician should evaluate the stability, flexibility, and strength of the commonly injured body sites (e.g., shoulder, hand and wrist, and lower extremities) as well as the trunk. Special attention should be made during the PPE for skin breakdown on insensate pressure areas (e.g., buttocks and back) as well as sites that come in contact with orthotics/prosthetics. A careful history of heat/cold injuries and changes in neurologic function should also be solicited [5].

Additional musculoskeletal testing is recommended for limb-deficient athletes due to amputations or congenital deformity. The musculoskeletal examination of an individual, who has had a lower extremity (LE) limb deficiency, should assess the stability, flexibility, and strength of the trunk, as well as the hip girdle and the unaffected and affected LE with and without the prosthesis. For individuals with upper extremity (UE) limb deficiency, the stability, flexibility, and strength of the shoulder girdle must be assessed in the unaffected and affected extremity with and without prosthesis, in addition to a trunk and LE evaluation [5].

Careful evaluation of the athlete's wheelchair, prosthetics, orthotics, and assistive/adaptive devices should also be performed prior to competition.

This is usually facilitated by consultation with the individual's orthotist, prosthetist, or other health-care specialists with experience in this area [5].

In summary, pre-participation evaluation of the adaptive athlete should encompass all the aspects of the able-bodied clearance exam but with additional attention paid to key areas of unique concern to that individual athlete. A comprehensive, systematic, and multidisciplinary team approach is critical to identifying and managing both disability-related and non-disability-related conditions in the adaptive athlete.

Medical Complications

Physicians covering adaptive sporting events experience a high volume of visits to the medical treatment area and significant acuity of medical conditions. For instance, 82% of participating athletes at a recent Paralympic Games utilized provided medical services most for prior existing medical conditions [7]. The general medical conditions and category-related injuries that adaptive athletes experience are covered here in this chapter, while sport-specific considerations and injury patterns are covered separately and in greater depth in the following chapters.

Spinal Cord Injuries

Most wheelchair athletes have spinal cord injuries; however, athletes with a deficiency of multiple limbs due to amputations or congenital deformity, cerebral palsy, polio, or other neurologic disorders are eligible to compete in this category. The conditions experienced by athletes with spinal cord injuries may be applicable to other wheelchair athletes, depending on the extent of trunk and upper extremity function, level of sensation, and preservation of bowel and bladder function [8].

General (Thermoregulation)

The extent of the thermoregulatory impairment is directly related to the level of SCI. Loss of motor and sensory function as well as lack of control of autonomic function (dysautonomia) can inhibit cardiovascular and thermoregulatory functioning. Loss of blood flow regulation via the CNS, loss of temperature sensation, and inability to sweat or shiver below the level of injury prevent autonomic control of temperature regulation. Therefore, depending on the environmental conditions, these athletes are at much higher risk of both hypothermia and hyperthermia. Event medical support teams should be aware of wet clothes and prolonged pool time even in normal ambient temperatures. In warm environments precooling and cooling strategies during competitions can reduce thermal strain and improve functional capacity [9].

Dermatologic

As many athletes with SCI are often insensate below the level of injury, the examiner needs to pay particular attention looking for occult injuries (pressure sores, fractures, dislocations, and visceral injuries). Prolonged pressure over bony prominences combined with shearing forces from activity and moist, insensate skin can cause local tissue ischemia and injury. Athletes in wheelchairs who have a pressure ulcer should not be cleared for sports participation until there is complete healing of the wound [4]. Frequent monitoring is key to pressure sore prevention. Prevention tactics include skin checks, shifting of weight every 15 min to relieve pressure, the use of appropriately fitting seat cushions, and maintenance of a dry environment. Cold weather injuries (frostbite) are of particular concern as athletes with spinal cord injuries have impaired sensation and require frequent visual monitoring [8, 10].

Nervous System

Autonomic dysreflexia (AD) is a medical emergency caused by unregulated sympathetic outflow due to interruption of neural pathways after spinal cord injury at or above the level of T6. Noxious stimuli below the level of injury can cause reflexive sympathetic activity that cannot be modulated by supraspinal centers of control, resulting in high levels of sympathetic activity below the level of injury and incomplete parasympathetic compensation above the level of injury. Symptoms include headache, skin flushing, piloerection, and diaphoresis above the level of spinal cord injury [8]. If suspected the athlete should be immediately removed from competition or activity. Treatment should include sitting the person upright, removing restrictive clothing, and searching for the source of the noxious stimulus, which is commonly a distended bladder or impacted colon, pressure sores, or other injury [8]. Transportation to an appropriate facility for further management should be a strong consideration. For acute blood pressure control, chewable nifedipine or nitro paste can be used [10]. Most athletes know the danger of intentionally causing AD, which is banned by the International Paralympic Committee. Therefore, the practice "boosting," which is an effective ergogenic aid [11], is rarely employed.

Wheelchair athletes (WCA) are at a significantly increased risk of upper extremity entrapment neuropathies, with the most common being carpal tunnel syndrome with reported prevalence rate of greater than 50% [10]. Prevention techniques include maintaining a relaxed rather than a firm grip to minimize the increases in intracarpal pressures experienced during propulsion. Use of padded gloves for skin protection is a common practice; however, it may not be effective at preventing carpal tunnel syndrome. Perhaps the second most common upper extremity neuropathy observed in WCA is ulnar neuropathy at Guyon's canal or the cubital tunnel which may cause pain and weakened grip strength. Racquet sports may place WCA at increased risk. Counterforce braces, emphasis on proper technique, and use of appropriately tensioned racquets may assist with prevention of ulnar neuropathy [12].

Orthostatic hypotension (OH) occurs in most SCI patients and is caused by decreased sympathetic efferent activity in the vasculature below the level of the injury resulting in venous pooling. Symptoms include light-headedness and dizziness; syncope may occur if uncorrected. Prevention includes lower limb compression stockings and abdominal binders, maintenance of hydration, and salt supplementation [10]. Nonpharmacologic prevention should be attempted before the use of pharmacologic agents for wheelchair athletes who experience orthostatic hypotension. Pharmacologic treatment with World Anti-Doping Agency (WADA) banned stimulants (midodrine, fludrocortisone, or ephedrine) are often helpful but would disqualify the athlete from competition [10]. For a list of banned substances visit the WADA website (www.globaldro.com). Each organization has specific guidance regarding therapeutic use exemptions (TUE) for medications banned by WADA. TUE forms are available on the WADA website (www.wada-ama.org).

Musculoskeletal

Wheelchair athletes are susceptible to the same overuse injuries experienced by able-bodied athletes. However, their reliance on upper limbs for mobility and activities of daily living places significant importance on recognizing, treating, and preventing upper limb injuries. Their functional impairment is magnified compared with able-bodied athletes as relative rest to allow injuries of the upper limb to heal may not be possible. Additional treatment considerations should include splinting, orthotic prescriptions, home and equipment modifications, and additional assistance with home care. Sometimes admission to an inpatient facility is required to allow proper rest of the extremity.

Following traumatic brain injury (TBI), SCI, burns, and arthroplasty, heterotopic ossification (HO) or pathologic bone formation may develop around major joints and restrict range of motion. Up to 36% of patients with spinal cord injuries may develop HO [8]. Common areas affected are the hip joints, but the knee, elbow, and shoulder may also be impacted [10, 13]. Restricted motion and the presence of hardened bone within soft tissues can increase the risk of pressure sores and entrapment neuropathy.

Spasticity is velocity-dependent increase in muscle tone that occurs after injury to the upper motor neuron. It is a common complication of SCI which may limit athletic participation by interfering with voluntary movements and restricting range of motion. An increase in spasticity may be an indicator of an occult systemic condition. For example, infections, intra-abdominal pathology (e.g., appendicitis), skin breakdown, or bladder distension may be otherwise asymptomatic in an athlete with SCI. Therefore, a sudden increase in spasticity should lead to a search for underlying pathology. Treatment for spasticity includes oral medications (baclofen, dantrolene, tizanidine, benzodiazepines) or injectables such as botulinum toxin and intrathecal medications such as baclofen. If spasticity is resistant to conservative treatment, surgery for tendon lengthening may improve hygiene, activities of daily living, and functional activities including participation in athletics [8, 10].

Visceral

A common condition in wheelchair athletes is bladder dysfunction causing retention, often necessitating indwelling, suprapubic, or intermittent catheterization and resulting in increased rates of urinary tract infections and stone formation. The athlete may not adhere to appropriate frequency or technique of clean intermittent catheterization during competition events. Signs of urinary dysfunction include fever, fatigue, general sense of unease, discomfort, autonomic dysreflexia, incontinence, and an increased level of muscle spasticity [8]. Often times in SCI athletes the first sign of a kidney stone, urinary retention, or infection may be signs of AD.

Bowel dysfunction is another condition common to wheelchair athletes. These athletes need to maintain their regular bowel programs for effective defecation and avoidance of incontinence. Again during competition events it is important to adhere to appropriate timing of their bowel program. One goal would be to time the bowel program to evacuate the bowel prior to competition to avoid any effect on performance. Clinicians should counsel athletes on the importance of bowel and bladder management, which has significant performance and practical implications. Athletes should also be counseled to undergo slow alterations in bowel management to best accommodate their expected competition schedule at upcoming events and to always be cognizant regarding the available facilities for bowel and bladder management at each venue [8].

Limb-Deficient Athletes

General

Athletes with partial or full loss of limbs are eligible to compete under the classification of athletes with limb deficiency. Limb deficiency may be due to congenital, traumatic or acquired (usually due to chronic) conditions and involve the upper limbs, lower limbs, or both. The nature of limb loss and associated conditions will lead to clues to the overall health of the athlete.

Dermatologic

Athletes with limb deficiency (AWLD) are at risk for developing several skin disorders as the distal portion of the residual limb transitions to a weight-bearing surface. An adequately healed incision is necessary before prosthetic gait training and advancement to recreational and sports activities. This is key as AWLD may require surgical revisions and must be patient with wound healing before returning to play. Common skin conditions associated with prosthetic use include ulcers, inclusion cysts, calluses, contact dermatitis, hyperhidrosis, verrucous hyperplasia, lichenification, and infections [8, 10, 13, 14]. When these complications occur, medical management and prosthetic adjustments are often necessary.

As shear forces generated across the skin within a prosthesis increases, the lower the pressure required to cause tissue breakdown [14]. Pressure and shear forces can easily rise to tissue-damaging levels causing ulcerations during training and competition. AWLD with impaired sensation in the residual limb combined with exertional sweating can make skin breakdown more likely. Proper socket fitting, silicone liners, padded sleeves, socks, and additional padding can help prevent injury. Some athletes may prophylactically treat their residual limb with an antiperspirant to decrease the amount of perspiration [10]. Relative rest of the residual limb while treating ulcerations may allow the athlete to be ambulatory while waiting for the ulcer to heal.

Verrucous hyperplasia is a wartlike lesion that may develop at the distal end of the residual limb. It may occur as a result of proximal residual limb constriction leading to vascular compromise or from chronic bacterial infection. Prevention consists of equal distribution of pressure through the residual limb, as in a total contact socket. Shrinker socks and modification of the socket to apply appropriate pressures to the distal end may also help to resolve this problem. Topical antibacterial agents can be used for bacterial overgrowth [14].

Overall, the best treatment of dermatologic issues is prevention, which can be achieved through education, close monitoring of prosthesis fit, strategic timing of donning a prosthesis, considerations of the time out of the prosthesis and liner, and responding to environmental factors [10].

Nervous System

A neuroma occurs at the distal end of a transected nerve which is often the case in the residual limb of an amputee. A neuroma at or near a weight-bearing structure can create paresthesia, dysesthesia, and radiating pain when exposed to pressure. Thus limiting ambulation, weight bearing, and the athlete's ability to train and compete. Treatments include prosthetic modifications to relieve pressure on the neuroma, oral antiepileptics and tricyclic antidepressants, and injection of corticosteroids. Surgical resection may be an option if conservative treatments are unsatisfactory [8, 10].

Musculoskeletal

Heterotopic ossification (HO) which typically develops within the first 6–12 months after amputation is the formation of bone in tissues that are not normally ossified. Traumatic brain injury (TBI), spinal cord injury (SCI), burns, and total arthroplasty and residual limbs after traumatic amputation are risk factors for developing HO [8]. HO in residual limbs may increase the risk of skin breakdown or cause pain with weight bearing. Socket modification to accommodate the ectopic bone may alleviate symptoms. Monitoring for skin breakdown should be increased in limb-deficient athletes with HO. If conservative measures are unsatisfactory, surgical excision of the ectopic bone may be required to restore adequate levels of function [8, 10].

Cerebral Palsy (CP)

Fifty percent of athletes with cerebral palsy participate in wheelchair sports and the other 50% are ambulatory [11]. Athletes with impairments resulting from stroke or traumatic brain injury are often placed under the CP classification. In addition to movement-related limitations, they may also have disturbances of sensation, cognition, communication, perception, and behavior. However, as this category covers a broad spectrum cognition may be fully intact [8]. Because of intracranial pathology, these athletes may have also have seizure disorders.

Disorders of speech, hearing, and vision can impact the ability to communicate. Athletes with communication or cognitive disorders might not readily report symptoms of heat or cold intolerance [15]. Athletes with high supportive needs are less able to take fluids during sports without assistance [15]. Although CP is not normally associated with impaired thermoregulation, these athletes may need increased oversight to prevent heat and cold environment-related injuries.

Dermatologic

Athletes with CP are subject to the same dermatologic conditions as wheelchair athletes (SCI). Pressure sores and skin breakdown in flexural creases can interfere with training, competition, and activities of daily living. Athletes in wheelchairs who have a pressure ulcer should not be cleared for sports participation until there is complete healing of the wound [4]. Preventing skin breakdown with frequent position changes, padding vulnerable areas, bracing, and diligent monitoring are the keys to keeping these athletes in the game.

Nervous System

Epilepsy affects approximately half of all patients with cerebral palsy [8]. Although athletes with CP have higher rate of seizure disorders than able-bodied athletes, there is minimal risk of exertional seizure; therefore, participation is permissible if seizures are well controlled [4]. However, stress from intense training or dehydration might induce seizures [4, 7, 15]. Therefore, the sports medicine physician should individually assess athletes with poorly controlled seizures for fitness for participation in higher-risk sports. Antiepileptic drugs may contribute to the risk for thermoregulatory impairment, impaired vision, and decreased bone mineral density [8].

Cardiovascular

The average athlete with CP has decreased cardiorespiratory endurance and expends more energy than their able-bodied counterparts due to reduced muscle volume and desynchronization of agonist/antagonist muscle groups [8]. However, at the elite level, athletes with CP may have the capability to achieve a more equitable exercise response [16].

Musculoskeletal

Athletes with CP have difficulty with motor coordination due to spasticity, ataxia, and involuntary movements (athetosis). Anterior flexor muscles usually have more strength than the posterior extensors. This muscle imbalance reduces flexibility and functional strength.

The topic of spasticity that is also covered in wheelchair athlete section above is a common musculoskeletal complication in athletes with CP. The increased velocity-dependent muscle tone necessitates stretching to maintain range of motion but if done too close to activity can impair performance. Stretching, started after a period of warm-up, should be slow and sustained to prevent activation of stretch reflex [11]. Botulinum toxin can be used in the management of spasticity, remember any medical treatment that improves function can also change the athlete's classification [15, 17].

Athletes with CP are at increased risk for overuse syndromes, muscle strains, and patellofemoral pain syndromes because of muscle imbalances [11]. Hip development is typically poor in persons with cerebral palsy and can cause acetabular dysplasia and hip subluxation [8].

Osteopenia is common among athletes with CP, given the combination of antiepileptic drugs, lack of mobility, and nutritional deficiencies complicating their condition. Seventy-seven percent of persons with moderate to severe CP have reduced bone mineral density (BMD). Therefore, athletes with cerebral palsy should have BMD assessed and deficiencies addressed before participation in contact sports [8].

Medications

Neurostimulants such as modafinil or methylphenidate are often prescribed after traumatic brain injury. These place the athlete at increased risk for arrhythmia and heat exhaustion. Likewise, anticholinergic medications used for treatment of neurogenic bladder can also increase susceptibility to heat-related illness. Many of the medications prescribed for this population are banned by WADA; therefore, they require therapeutic use exemptions (TUE). Each organization has specific guidance regarding TUE for medications banned by WADA. For a list of banned substances, visit the WADA website (www.globaldro.com). TUE forms are available on the WADA website (www.wada-ama.org) [8].

Visually Impaired

Legal blindness refers to visual acuity of 20/200 or less in the better eye even with correction or an angular field of vision no greater than 20° [11]. Visually impaired athletes may possess a number of different conditions that limit visual acuity; therefore, this category could potentially include a broad range of medical conditions ranging from isolated ocular trauma in an otherwise healthy person to congenital and acquired syndromes also affecting sight.

Musculoskeletal

Athletes with visual impairments may be particularly prone to acute injuries of the distal, lower extremities. Visually impaired athletes also may be at risk for chronic overuse injuries due to altered biomechanics, induced by poor proprioception and loss of the visual component of balance [8].

Intellectually Disabled Athletes

Intellectually disabled athletes (IDA) frequently have underlying ocular and visual defects, congenital cardiac anomalies, and atlantoaxial instability that predispose them to injuries [1]. The most common diagnoses discovered during the PPE are vision loss (15%) and seizures (16%) [3]. Obesity affects about half of all IDA, while hypothyroidism and sleep apnea are primarily found in adults with Down syndrome, 40 and 50%, respectively [18].

General (Thermoregulation)

Antiepileptic medications commonly taken by IDA may cause thermoregulatory impairment. Additionally, athletes with communication or cognitive disorders might not readily report symptoms of heat or cold intolerance; therefore, the sports medicine team must be vigilant for signs of heat- or cold-related injury.

Nervous System

Fifteen percent (range, 10–40%) of people with Down syndrome have atlantoaxial instability (AAI) [3]. Symptoms suggestive of AAI include easy fatigability, abnormal gait, neck pain, limited cervical range of motion, torticollis, incoordination, spasticity, hyperreflexia, clonus, extensor plantar reflex, sensory deficits, and other upper motor neuron and posterior column signs [4, 11]. The highest risk for AAI has been reported to be between 5 and 10 years of age [11].

Athletes with Down syndrome are at risk for spontaneous or traumatic subluxation of the cervical spine. Radiographic screening for AAI in asymptomatic athletes is controversial, because there is little evidence to suggest it is a significant risk factor for subsequent development of AAI. However, in addition to the PPE, lateral cervical spine radiographs in flexion and extension are required for all Special Olympians and are recommended for all patients with Down syndrome. Although a large majority of persons with Down syndrome who have radiographic AAI (defined by the Special Olympics as >4.5 mm of odontoid-atlas separation) are asymptomatic, all athletes with AAI should be restricted from participation in sports activities that pose a risk for neck injury or inherently require excessive neck flexion/extension [4, 8]. The above-listed neurologic signs and symptoms may be more predictive of risk of injury progression than radiographic abnormalities in asymptomatic athletes [3].

Atlanto-dens interval of less than 4.5 mm in asymptomatic individuals is considered to be within normal limits and tends not to change over time [11]. Therefore, annual radiographic evaluations are not necessary unless there has been an interim injury [3]. However, the Special Olympics as the governing body provides specific guidance for evaluation and participation.

Certain high-risk sports should be avoided if radiographic evaluation demonstrates AAI: diving, gymnastics, pentathlon, squat lift in powerlifting, high jump, soccer, alpine skiing, swimming using flip turns, butterfly stroke, diving starts, or any competitive event or warm-up exercise that places undue stress on the head and neck [4, 3]. Athletes with AAI must sign a Special Olympics waiver to participate in certain sports [19]. More details are available at (www.specialolympics.org).

Seizure disorders are common in people with intellectual disabilities, with about 26% affected. Special Olympics guidance to clinicians warns of anecdotal reports of athletes purposefully skipping doses of antiepileptics in order to improve athletic performance [19]. As with CP the sports medicine physician should individually assess athletes with poorly controlled seizures for fitness for participation in higher-risk sports.

Cardiovascular

Cardiovascular conditions are prevalent among athletes in this category. Approximately half of all persons with intellectual disabilities have congenital heart problems, and most common is atrioventricular canal defects. Also, due to chronotropic incompetence, the peak heart rate is only 84–85% of the age-predicted maximum for males and females with Down syndrome [3]. Although as with CP [16] some studies suggest that exercise training may improve the deficit [11]. Fragile X syndrome is associated with mitral valve prolapse and aortic root dilatation [8].

The high prevalence of cardiac defects and the use of medications that may induce a dysrhythmia place these athletes at much higher risk for sudden cardiac death than the general population. Therefore, clinicians should obtain a detailed history soliciting input from caregivers and consider further screening when indicated. Cardiac testing including stress testing and echocardiography may be necessary [8].

Musculoskeletal

Likely due to a combination of inherent collagen and bone abnormalities and effect of antiepileptic medications, low bone density occurs in 20% of Special Olympics athletes [19]. Although injury rates for IDA are generally lower than the general population, ligamentous laxity can lead to common disorders. About 5% of athletes with Down syndrome will have acquired hip instability leading to recurrent dislocation, while patellofemoral dislocation occurs in 4–8% of athletes. The common foot and ankle conditions, pes planus and hallux valgus, are not generally bothersome when treated with appropriately fitting shoes [18].

Medications

Athletes with intellectual disabilities commonly take antipsychotic and antiepileptic medications which are associated with weight gain, sun sensitivity, long QT syndrome, thermoregulatory impairment, impaired vision, and decreased bone mineral density. Appropriate pre-participation evaluations, proper referrals, and monitoring throughout participation enable identification and early intervention.

Les Autres

As discussed in the classification chapter, athletes in this category could have a range of different congenital and acquired conditions and syndromes. Some of these include multiple sclerosis, osteogenesis imperfecta, muscular dystrophy, and dwarfism [8]. A team approach to assessment and care of these athletes is often necessary given the complexity of conditions. Sports medicine physician's assessment of the athlete's condition and impact on thermoregulation, dermatologic, nervous system (seizures), cardiovascular, musculoskeletal, visceral, and medications will enable informed recommendations regarding the choice of sport and pre-competition planning in order to enable a safe environment for the maximum number of participants.

Injury Prevention and Treatment

The injury patterns for adaptive athletes are similar to those for able-bodied participants [7]. This is likely because all athletes are subject to similar biomechanical stress and complications from physical exertion. However, adaptive athletes may have specific conditions caused by or result from a disability leading to increased risk of particular injuries and complications.

For example, lower extremity injures are more common in ambulatory athletes (limb deficient, visually impaired, cerebral palsy) [7]. Fifty-three percent of injuries reported by athletes from the United States Association for Blind Athletes (USABA) were to a lower extremity [11]. Upper extremity injuries are more frequent in athletes who use a wheelchair [7]. The injuries reported by United States Cerebral Palsy Athletic Association athletes involved knee (21%), shoulder (16%), forearm/wrist (16%), and leg/ankle (15%) [11]. It is also common for the limb-deficient athlete to sustain injury to the intact limbs as well as the spine from repetitive compensation for the loss of limb function. Cervical and thoracic spine injuries are commonly seen in individuals with upper extremity amputations due to strength, weight, and activity imbalances and unequal movements. Likewise, lower extremity limb-deficient athletes often have low back pain as a result of excessive lumbar spine lateral flexion (side bending) and extension.

Increased injuries to the intact limb are also a concern. The athlete may increase the stress applied to the intact limb resulting in overuse injuries such as plantar fasciitis, Achilles tendonitis, or stress fractures [1]. Therapy focusing on core and back strengthening and flexibility can assist in minimizing these problems [1]. Also maximizing the use of assistive devices and ensuring proper ergonomics of training and competition equipment may prevent injuries caused by abnormal forces.

Environmental Illness

Many adaptive athletes are at higher risk for heat-, cold-, and altitude-related environmental injuries for a combination of reasons. Intrinsically some may have a disruption of neuro-regulatory systems involved in control of body temperature. Many are taking medications that further inhibit thermoregulatory function and increase dehydration risk.

Prevention requires heightened awareness and monitoring, use of appropriate clothing and equipment, availability of rehydration, and avoidance of extremes of temperature when possible.

Frostbite is of particular concern for insensate athletes during cold weather events. Athletes with SCI and athletes with impaired communication require frequent visual monitoring to prevent cold injuries.

In many winter sports, competition at high altitudes may precipitate acute mountain sickness (AMS). AMS involves a constellation of symptoms (headache, nausea, weakness, shortness of breath) and occurs with exposure to high altitudes. Given their altered neurophysiology and anatomy, athletes with spinal cord injury may be at higher risk of developing AMS. Acetazolamide may be used as prophylaxis in high-risk scenarios. Definitive treatment is decreasing altitude, while supplemental oxygen, acetazolamide, and dexamethasone are temporary adjuncts [10].

Conclusion

Physicians caring for adaptive athletes must be prepared to treat medical conditions common to the respective six categories and have a fundamental understanding of the unique biomechanics of the athlete and adaptive equipment required for participation. Clinicians can then apply preventive and rehabilitative principles to both prevent, treat, and rehabilitate injury and illness. This may require a multifunctional team of medical and equipment management professionals to properly care for adaptive athletes. With proper preparation, support, and knowledge, adaptive sports can be safe, fun, and inclusive.

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6 Emergent Care of the Adaptive Athlete

Ahmer Khan, Kevin Blythe, and B. Elizabeth Delasobera

Introduction

The number of individuals with disabilities participating in athletics, either in competition or for recreation, continues to increase, as technology improves to allow participation. As of 2014, it is estimated that about 2 million individuals with disabilities participate in recreational sports [1]. The growth of the Paralympic Games, from 16 participants in 1948 to greater than 4000 in 2012, reflects the larger overall growth in participation [2]. As participation continues to increase, it is important that medical providers become comfortable managing the acutely injured adaptive athlete on the field and in a medical setting. These athletes incur many of the same emergent injuries that other athletes suffer from, such as overuse musculoskeletal injuries, extremity fractures, traumatic brain injury, heat illness, and cardiac disease. There are also unique injuries to these athletes based on their disability and their sport of competition. The provider caring for these individuals must be comfortable with the basic principles of evaluation and management of acutely injured individuals. They need to also be mindful of the unique injuries and factors that should be considered when managing the individual athlete, with their specific disabilities. This chapter will discuss a basic approach to emergency care, placing special emphasis on the aspects of care that make these individuals unique.

Emergency Department Care

The initial approach to any patient evaluated in the emergency department starts with the assessment of the patient's airway, breathing, and circulation (A, B, Cs). The remainder of this chapter will go through the specifics of evaluating each one of these systems. Using this systematic approach reminds the provider to pay particular attention to the critical life-enabling systems initially, without being distracted by more periph-

A. Khan, DO, CAQSM (✉)
Baylor Scott and White—Plano, Plano, TX, USA
e-mail: ahmerk08@gmail.com

K. Blythe, MD • B.E. Delasobera, MD, CAQSM
MedStar Washington Hospital Center, Georgetown University, Washington, DC, USA
e-mail: bronson.e.delasobera@medstar.net

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_6

eral injuries that may not carry the same immediate mortality risk. Any disorder detected during this primary survey should be immediately addressed before proceeding forward with the survey. Assessment of the A, B, Cs is followed, naturally, by D—evaluation of neurologic disability—and E exposing the patient. This initial primary evaluation of the patient should be followed by a systematic and thorough secondary head-to-toe evaluation, looking for signs of injuries that may not be immediately apparent on the primary survey.

After establishing the stability of the patient, it is important to gain as much information about the mechanism of injury as possible. This information alerts the provider to have a higher index of suspicion for certain injuries that follow a certain mechanism of injury. Family, coaches, and EMS who were at the scene may be great additional resources to get an understanding of the injury. This history should also include general health information such as comorbid conditions, medications, prior injuries, extent of prior disability, and allergies, as this will affect your work-up and treatment plan.

It is important to get an initial set of vital signs to assess for the stability of the cardiopulmonary and thermoregulatory status of the injured or ill athlete. Many of these will be part of the primary survey—respiratory rate (RR) and oxygen saturation during the assessment of the patient's breathing and blood pressure and heart rate during the circulatory evaluation. It is important to obtain the injured athlete's temperature, including a rectal temperature if the athlete is altered or you have a high suspicion for heat-related or cold-related illness. According to a 2002 review, rectal temperature remains the most accurate way of measuring core temperature in the athlete [3]. Especially in the altered or confused patient, consider finger-stick glucose as an additional vital sign. Failure to recognize and respond to hypo- or hyperglycemia may cause poor outcomes for the patient. Remember to get a new set of vital signs if there is any change in clinical condition or any significant intervention was done.

In any acutely injured patient, it is important to obtain intravenous (IV) access for laboratory testing, administration of intravenous contrast for imaging, medication administration, and intravenous fluid rehydration. While a single IV may be sufficient in many patients, in a hypotensive patient or one who is acutely ill, two large bore IVs may be required for adequate resuscitation. If unable to provide access via an IV line, intraosseous access is an alternative method to provide medication and resuscitation fluids to patients.

Airway

The assessment of an acutely ill or injured individual should begin with the determination if the patient has a patent and protected airway. A patent-protected airway is necessary for oxygenation and ventilation, as well as to prevent aspiration of gastric contents. It is important to first observe for anatomic deviations that may cause mechanical obstruction of the airway, such as a large neck hematoma or posterior displacement of a fractured maxilla and midface. Further evaluation should be completed to assess the functionality of the airway. A quick approach that is recommended to determine if the airway is patent is to have the patient verbally respond to a question. This simple response informs the provider that the patient (1) has no upper airway obstruction, allowing them to transmit air through the vocal cords, and (2) has a high enough level of consciousness to listen, integrate data, and give an appropriate response. This approach is not appropriate for the hearing impaired or individuals who are nonverbal at baseline secondary to a previous stroke or intellectual/social impairment. Another reliable indicator of a patent airway is the patient's ability to swallow their own secretions. A patient with pooling secretions in the airway, copious drooling, or gurgling respirations is not maintaining a patent airway and may need urgent intervention to establish one. Additionally, the provider can listen for stridor, which may indicate an upper airway obstruction or vocal cord dysfunction. Historically, the absence of a gag reflex has been described as an indicator of someone failing to maintain an airway. However, 12–25% of normal adults have an absent gag reflex, making this technique less useful than the other's previously discussed [4].

Patients with cerebral palsy, or other neurologic disorders affecting the brainstem, may have diminished airway reflexes at baseline. It is important to keep this in mind and minimize any aspiration risks [5]. With cerebral palsy affecting muscles of movement, posture, and swallowing, approximately 90% of patients with CP have some degree of oropharyngeal dysphagia. This inability to consume sufficient food and fluids safely can lead to respiratory complications and has a direct correlation with the severity of gross motor skill function [6].

The first step in helping to keep the airway patent is to have the patient in a neutral airway position, such as the "sniffing position." Lifting the chin superiorly places the neck in a slightly extended position placing the upper airway into a more neutral open alignment (Fig. 6.1) [7].

In the past for helmeted and padded athletes, the recommendations were always to leave equipment on for transport and to access the chest or face by removing only the front of the pads or face mask, respectively [8]. Recently, recommendations have advised that prehospital providers or sideline physicians *can* and in some cases *should* remove helmets and other protective equipment *prior* to transport to a primary emergency facility [9]. Recent research has demonstrated basic life-support skills including chest compressions and ventilations may be compromised in the setting of athletic equipment [10]. However, this is still a very controversial topic, and equipment removal needs to be done in the hands of an experienced provider. If there are ample prehospital and experienced physician providers on the sideline and the equipment can be safely removed, then this would be the recommendation. Otherwise, waiting until after transport, especially if there are no life-threatening injuries, should be considered.

The jaw thrust maneuver helps to prevent posterior deviation of the tongue into an obstructing position in the oropharynx. Moving the angle of the mandible anteriorly lifts the base of the tongue forward and away from the posterior oropharynx, without the manipulation of the cervical spine that can occur with the head tilt-chin lift. The helmet has been cited as complicating jaw thrust maneuvers or providing bag-valve mask placement for ventilations, along with the chin strap obstructing a proper seal for the mask [11].

In addition to opening the airway with jaw thrust, it is important to look into the airway for any source of obstruction: a mouth guard, gum, a displaced tooth, etc. It is no longer recommended to perform a blind sweep of the oropharynx; but if an obstructing object is visually identified, using a finger sweep or forceps to remove an obstructing object is definitely indicated.

If these maneuvers are not sufficient to maintain a patent airway, or the provider suspects that the patient's clinical condition may continue to deteriorate, it may be necessary to provide an airway adjunct to maintain patency. A nasopharyn-

Fig. 6.1 Lifting chin to place in sniffing position and open airway

geal airway may be placed in a sedated or awake/alert patient to allow oxygenation/ventilation past an oropharyngeal obstruction. Note that this technique is contraindicated for a patient with a suspected midface fracture. An oropharyngeal airway can also be used in this matter but will not be tolerated in the awake patient. Ultimately these techniques are temporizing maneuvers. Patients that require this level of intervention will likely need to have an advanced airway placed that is secured allowing oxygenation/ventilation while protecting the patient from aspiration of gastric contents. Supraglottic airway devices can be placed quickly using a blind technique. These devices provide an airway until a definitive secure airway can be established safely. Placement of an endotracheal tube using a rapid sequence intubation (RSI) technique should be attempted when it is clear that the patient will need prolonged airway or ventilatory support. The patient's hemodynamic and oxygenation level should be optimized prior to any intubation attempt, unless the patient is acutely declining and not able to be oxygenated or ventilated with bag-valve mask and adjunct airway ventilation (Fig. 6.2) [12].

Evaluation of the airway is paramount in emergency department assessment. Athletes with hearing or communication impairments may not give the same auditory confirmation of airway patency that is generally tested. It is important to look and listen for other signs of airway obstruction before proceeding to the next step of the primary survey.

Breathing (Respiratory)

Assessment of the patient's respiratory status begins with observation of the patient's overall work of breathing—keeping in mind that they may have just been participating in a physically taxing activity. Tachypnea, costal retractions, and use of accessory respiratory muscles are all signs of increased work of breathing. Auscultate the lungs for unequal breath sounds or wheezing. Unilateral, absent, or diminished breath sounds may indicate hemothorax or pneumothorax depending on the mechanism of injury. Diffuse wheezing in an athlete may be due to exercise-induced asthma, but may be due to an acute exacerbation of chronic asthma, a severe allergic reaction, or from an exacerbation of chronic obstructive pulmonary disease (COPD). The remainder of the history and physical should help to put these lung exam findings in the proper context.

Pulse oximetry is an important adjunct in assessing the functionality of breathing—provid-

Fig. 6.2 Various airway adjuncts

ing oxygen to the tissues. It is important to provide supplemental oxygen via nasal cannula or non-rebreather face mask in order to maintain oxygen saturations greater than 95%. As oxygen saturations fall below 90%, arterial oxygen concentration and tissue oxygenation decrease precipitously. If a patient has underlying lung disease, such as COPD, their underlying normal oxygen saturation may normally be around 92%. In this case tolerating a lower oxygen saturation close to their baseline would be appropriate.

If the patient has significant respiratory distress, tracheal deviation and/or absent breath sounds contralateral to the direction of tracheal deviation, the provider must strongly consider the likelihood of a tension pneumothorax. Tension pneumothorax is a life-threatening emergency that could ultimately lead to cardiopulmonary arrest. Needle decompression or thoracostomy is indicated in this setting.

Patients who are not making any spontaneous respiratory efforts or are only taking agonal breaths require ventilation via bag-valve mask, with or without airway adjuncts as previously described. Per ACLS guidelines, a respiratory rate of 10–12 breaths per minute is sufficient for most patients. Further ventilator management is beyond the scope of this text.

Circulation

Evaluation of the cardiovascular system starts with assessment of pulses. Absence of a carotid or femoral pulse after 10 s should prompt the initiation of ACLS techniques beginning with chest compressions and acquisition of a defibrillator. Next should be checking for peripheral perfusion in each of the extremities, done by palpating distal extremity pulses and looking for cool, cyanotic, or mottled extremities. Other signs of impending shock include tachycardia, diaphoresis, and significant external hemorrhage.

Blood pressure obtained manually or with an automated device is used as a quantifiable surrogate for tissue perfusion. Ideally the patient's mean arterial pressure (MAP) will be greater than 65 mm Hg, allowing for appropriate perfusion to the brain. If the patient has signs of shock on exam or a significantly decreased blood pressure, then resuscitation, beginning with intravenous fluids and then blood products, is required. Shock in the athlete can be caused by hypovolemia, hemorrhage, infection (sepsis), anaphylaxis, cardiac/pulmonary injury, or spinal cord injury (autonomic dysfunction). Wheelchair-bound individuals may have infected pressure ulcers over the sacrum, coccyx, or ischial tuberosities that may be an occult source of infection. These should be adequately treated with appropriate intravenous fluids, broad-spectrum IV antibiotics, proper wound care, and surgical evaluation as deemed necessary.

Individuals with high spinal cord injuries often have impaired sympathetic nerve activity, due to disruption of the paraspinal sympathetic chain. At baseline, there is a general state of parasympathetic dominance, resulting in a decreased cardiac output and relative hypotension. These individuals may have episodes of autonomic dysreflexia, which is a condition where they can have surges of significantly elevated blood pressures [13]. For reasons not completely understood, but involving cerebral remodeling and loss of supraspinal inhibitory control after an acute spinal injury, irritation of gastrointestinal or urinary system can result in an unopposed sympathetic-like response resulting in elevated blood pressures. Competitive athletes with spinal cord injuries may attempt to voluntarily induce an autonomic dysreflexic response. This is termed as “boosting” [14]. One technique described is intentionally clamping their indwelling Foley catheter. This results in bladder distension, which triggers a sympathetic-like surge that may boost their performance. While there are few studies to show predictable harm or improved athletic performance with this technique, there are numerous case reports of myocardial infarction, intracranial hemorrhage, and seizure. Current guidelines suggest treating autonomic dysreflexia by elevating the patient's head, loosening all clothing, and evaluating for any urinary system or bowel obstruction, including urinary tract infection, which may be causing the elevated blood pressure [15].

Orthostatic hypotension is another frequent complication that should be recognized and addressed in the adaptive athlete with high spinal cord injuries. It results due to decreased sympathetic efferent activity in vasculature below the level of the injury and also due to decreased reflex vasoconstriction. The result is venous pooling in dependent areas (lower limbs or abdomen) that occur with changes in position [15]. Symptoms may include light-headedness, dizziness, and syncope. Treatment is aimed at elevating the legs and pelvis approximately 45° from ground level in the acute setting. For repeated occurrences, pharmacologic treatment with midodrine, fludrocortisone, or ephedrine may be helpful. Prevention includes the use of lower limb compression stockings, abdominal binders, maintenance of hydration, and salt supplementation [15].

Recognizing signs of shock and preventing end organ damage due to poor perfusion is one of the critical roles of the emergency medicine physician. Normal blood pressure measurements may be different in individuals with sympathetic nervous system derangements, making it important to pay attention to other signs of poor perfusion. Physical exam, lactic acid measurements, and other lab testings can help to determine the perfusion for each individual patient.

Disability

After identifying any immediate life-threatening abnormalities, going through the A, B, Cs, it is important to take a snapshot of the patient's neurologic function. Usually this means using the Glasgow Coma Scale (GCS) to give an objective measure of the patient's global neurologic status. Originally published in 1974 by a pair of neurosurgery professors from Scotland, the scale was designed to assess the level of consciousness of patients with traumatic brain injury in an ICU setting [16]. Since then it has been used by first aid personnel, emergency medical services, and physicians in establishing the mental status of all acute medical and trauma patients. The score has three components: eye opening, verbal, and motor response as seen in Fig. 6.3 [17].

There are obvious limitations to using this scale in certain populations. Failure to recognize individuals with hearing impairments may result in falsely lower GCS scores, as the patient may fail to follow verbal commands. Nonverbal individuals cannot have an overall GCS score, since their verbal component will be abnormal at baseline. It is important to have an understanding of the baseline neurologic exam of patients with spinal cord injuries,

	1	2	3	4	5	6
Eye	Does not open eyes	Opens eyes to painful stimuli	Opens eyes to voice	Opens eyes spontaneously	N/A	N/A
Verbal	Makes no sounds	Incomprehensible sounds	Utters inappropriate words	Confused, Disoriented	Oriented, Converses normally	N/A
Motor	Makes no movement	Extension to painful stimuli	Abnormal flexion to painful stimuli	Withdrawal to painful stimuli	Localizes painful stimuli	Obeys Command

Best response = 15 (totally alert and oriented)
Comatose patient = 8 or less (requiring definite airway in proper clinical setting)
Totally unresponsive = 3

Fig. 6.3 Glasgow Coma Scale

cerebral palsy, multiple sclerosis, or other neurologic dysfunction. Another important concept to consider in the adaptive athlete is thermoregulatory disturbances that can alter his or her mental status. Below the level of the lesion, an athlete with a spinal cord injury can have impaired shivering to produce heat and impaired sweating and vasodilation to dissipate heat. It is expected that these athletes will have greater increases in body temperature with exertion, and greater decreases in temperature with exposure to cold weather, thus lowering their threshold for developing heat stroke and hypothermia, respectively [18]. The patient, family members, or coaches are great resources to identify any new neurologic changes from baseline. Specific extremity or nerve deficits are assessed during the secondary survey. At this point in the exam, only the patient's general level of alertness is being determined.

Conclusion

Evaluation of the acutely injured adaptive athlete follows the same principles of any emergency evaluation. Assessment of the athlete using the ABC mnemonic helps keep the provider focused first on life-threatening injuries. This is followed by a brief neurologic evaluation—using individuals familiar with the athlete to identify changes from the athlete's baseline along with considering potential environmental exposures. After this brief primary survey is complete, a more thorough head-to-toe evaluation of the athlete can be completed—keeping in mind to expose the patient to find any occult injuries or sources of infection. This general approach is the cornerstone of emergency evaluation, but it is important that the physician recognize the normal exam findings and specific injury patterns that the athlete may have based on their underlying disability and the sport that they are participating in. These will be discussed at greater length throughout this text.

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7 Surgical Considerations in the Adaptive Athlete

Kevin O'Malley, Tyler Kent, and Evan Argintar

Introduction

As the world of competitive sports continues to expand and evolve, there are more opportunities than ever for adaptive athletes. For example, the Paralympic Games are now the second largest sporting event in the world [1]. There are ten classes of participation based on impairment type, and there are various subclasses within each class. Competitions now recognize athletes with a range of disabilities from impaired muscle power, limited passive range of motion, limb deficiency, visual impairment, as well as to those with intellectual disabilities.

The benefits of exercise in this population appear to be numerous with multiple studies showing increases in quality of life, mental health, and physical health [2, 3]. As Dr. Ludwig Guttmann, founder of the Paralympic Movement, stated, "The aims of sport embody the same principles for the disabled as they do for the able-bodied; in addition, however, sport is of immense therapeutic value and plays an essential part in the physical, psychological and social rehabilitation of the disabled."

This diverse group of athletes presents unique challenges in the surgical management of their injuries. With such a diverse patient group, high quality research is limited. To complicate matters, many adaptive athletes are hesitant to undergo surgery for fear of adverse outcomes or a loss of independence. With an ever-growing need for treatment, clinicians are increasingly being called upon to treat this specialized population. Because this group of athletes requires such specialized care, there is a need for greater understanding of treatment strategies, expected outcomes, and therapeutic goals.

This chapter will explore published surgical outcomes, define the prevalence of injury based on impairment type and injury pattern, discuss the most common comorbid conditions and how they affect the postoperative course, and provide our recommendations for future steps to be taken to improve the care given to the adaptive athlete.

Surgical Outcomes

Introduction

There are few published research studies on surgical outcomes in the adaptive athlete. There are

K. O'Malley, MD
Department of Orthopaedics, Georgetown University Hospital, Washington, DC, USA

T. Kent, MD
Department of Orthopaedics, Penn State Hershey Medical Center, Hershey, PA, USA

E. Argintar, MD (✉)
Department of Orthopaedics, Washington Hospital Center, 106 Irving St. NW, Physicians Office Building Suite 5000 N Tower, Washington, DC 20010, USA
e-mail: Evan.Argintar@gunet.georgetown.edu

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_7

two possible reasons for this limited information. First, only recently has there been a demand for surgery in this group. The ability to perform at an elite level is a relatively new development in the world of adaptive athletics. The bulk of information relating to surgery focuses on maximizing quality of life, rather than enhancing performance. For example, rotator cuff repair in a wheelchair-bound patient is more commonly examined through the lens of ability to perform activities of daily living (ADLs) after surgery rather than the length of time before return to sport. Second, surgery in this group is a much more extensive undertaking. Not only can it be more difficult to heal from the surgery, but the further disability imposed by surgery imposes significant limitations on this population. Loss of function in one arm affects lifestyle in myriad ways [4]; ADLs, transfers, locomotion, and employment become nearly impossible without assistance. This makes adaptive athletes much less likely to undergo surgery simply for performance enhancement or the ability to return to sport.

Injuries encountered in adaptive athletes are most common in the upper extremity. Overuse injuries of the shoulder are especially common, and overhead sports are noted to be an independent risk factor for rotator cuff disease in paraplegic athletes [5]. Bicipital tendon injury, rotator cuff tears, and impingement syndrome are all common in adaptive athletes [6–8]. Elbow pain secondary to lateral epicondylitis, olecranon bursitis, and triceps tendonitis are seen in wheelchair athletes [9]. Upper extremity entrapment neuropathies are also very common at the carpal tunnel and Guyon's canal with some postulating that repetitive microtrauma is causative force. Prevalence of these neuropathies is estimated to be nearly 50% and most frequently encountered in the paraplegic weightlifters [7, 10].

While there is a wide range of possible upper extremity injuries in the adaptive athlete population, the majority of surgical outcomes research has focused on shoulder pathology. Paraplegics have a high prevalence of shoulder pain and injury with reported rates between 32 and 72% [6, 7, 11]. Shoulder injuries are especially common in adaptive athletes participating in track, road racing, and basketball [12]. This is an important consideration because nearly all adaptive athletes rely on at least one functional upper extremity for sport. For example, 16 out of 20 summer Paralympic sports use a wheelchair at least some of the time. Consequently, we will be referring primarily to the shoulder when we refer to surgical outcomes. However, while the shoulder is likely to be the most commonly encountered area of injury, it is not an exclusive focus; there are many possibilities that can present themselves. It is imperative that the surgeon and athlete collaborate to find the best solutions and extrapolate their approach based on the best available outcomes.

Before continuing, it is important to understand the issues that factor into the high prevalence of rotator cuff injuries (RCIs) and shoulder pain in wheelchair-bound patients. First, there is increased load on the shoulder when using a wheelchair with the shoulder becoming the weight- bearing joint of the body [13–18]. During transfers and wheelchair propulsion, the vertical forces on the shoulder increase by over 300% [19]. This significant force has been postulated to result in superior translation of the humeral head, leading to increased stress on subacromial structures ultimately resulting in RCI. Second, even in the healthy population, RCIs increase with age. This effect is exacerbated in paraplegics due to the increased loads and strain placed on their shoulders. Third, the level of spinal cord injury (SCI) can determine functionality and degree of impairment of the shoulder, and it is not uncommon to have referred pain from the neck that is felt in the shoulder [20, 21]. Thus, it is necessary to determine the correct source of pain prior to treatment.

We will now examine the most commonly reported metrics used to evaluate results and measure progress. As previously stated, there are very few clinical studies with reported surgical results. A literature review revealed only seven papers dealing with shoulder surgery in paraplegics. Five discussed rotator cuff repair and two discussed arthroplasty. There are several common themes that appear repeatedly and are similar to those reported in the literature related to non-impaired patients. These are the American Shoulder and Elbow Surgeons Standardized Assessment (ASES) score, Constant score, strength, range of motion, the role of radiography, patient demographics, and pain.

Outcome Scores

It is standard practice to employ objective rating scales as a means to determine functional outcomes. They allow the clinician to have a standard method to evaluate all patients, they remove bias, and they also streamline and balance subjectivity by using the same set of questions and rating scales.

Some of the most common rating systems are the ASES and Constant scores. The ASES score is a patient questionnaire that attempts to quantify pain, function, and disability. There are various scoring options, but the most common uses a 100-point scale with 100 being less pain and better function. The Constant score combines patient responses with clinical examination in order to assess pain, ability to perform activities of daily living, ROM, and strength. These scales are popular because they require little training to perform or evaluate, can be completed quickly, and are validated [22, 23].

Other scales used are the Neer and Functional Independence Measure (FIM) classifications. The Neer is based on the classic principles developed by Charles Neer over half a century ago and evaluates pain, motion, strength, function, and patient satisfaction. Results are reported as excellent, satisfactory, or unsatisfactory. The FIM gauges a patient's ability to function independently, and scores range from 18 to 126.

Outcomes

There were several problems encountered during review of available literature. First, outcome measures utilized vary widely. This made comparison difficult. Second, several studies did not use any objective measure but rather used subjective measures (e.g., "no improvement" versus "improved"). Third, follow-up duration varied widely with a range of 2.5–84 months [4, 11, 16, 24–27]. Lastly, many of the studies focused on the SCI population instead of the adaptive athlete population. Surgical repairs and physical healing occur at different intervals, and without a common follow-up time, it is impossible to compare results. However, overall trends were apparent for the two most reported surgeries: shoulder arthroplasty and rotator cuff repairs.

Arthroplasty

There are but two published papers on shoulder arthroplasty in paraplegic patients [25, 26]. Garreau de Loubresse et al. required a multicenter retrospective review in order to identify a total of five patients who had undergone the procedure. In total, 11 paraplegic patients in published literature have received shoulder arthroplasty. Thus, there is little formal guidance for those considering the procedure.

The two papers showed similar demographic data. The average age of the patient at the time of surgery was 70 and 69 years old. The average length of time they had been paraplegic prior to surgery was 20 and 41 years. Interestingly, all 11 patients were female. The average time of follow-up was 30 and 84 months. Garreau de Loubresse et al. did not comment on how many different surgeons performed the five cases, but seeing as it was a multicenter study there were likely multiple. Hattrup and Cofield reported five surgeons for six cases. However, there was not any commonality regarding the type of implant used. For example, some used cement while others did not, and multiple styles of implants were used. Hattrup and Cofield reported surgeries being performed from 1982 to 2006. They point out that there has been a significant evolution in technique and implants over that time. So, though the patient demographics were similar, the procedures performed were not [26].

Postoperative results are promising. Garreau de Loubresse et al. used both Constant and ASES scores to evaluate results. Absolute Constant score average improved from 30 to 52 (out of 100).

After adjustment for age and sex, an adjusted Constant score improved from 43.9 to 75.8. ASES score average improved from 28 to 37 (out of 55). Pain score average improved from 5 to 10 (out of 15, with 15 being pain-free). Hattrup and Cofield used a modified Neer classification which uses improvement in degrees of range of motion and subjective pain scales to rate outcomes as excellent, satisfactory, or unsatisfactory. One patient had an excellent outcome, four had satisfactory outcomes, and one had an unsatisfactory outcome. Thus, both groups had improvement in function and pain scores.

Complications varied, but eight of eleven patients had a reported complication. Garreau de Loubresse et al. reported two complications: the need for an early revision due to a technical error, and the migration of a cemented glenoid implant with resultant increase in pain and decrease in function. Hattrup and Cofield reported complications in five of six patients. However, they included complications not directly related to the arthroplasty (pressure ulcer, pneumonia in two patients, and ileus). Complications directly related to the procedure included the need for early reoperation due to an undiagnosed greater tuberosity fracture present at the time of surgery and a brachial plexopathy. Not unexpectedly, complication rates were high. However, this should not overshadow the fact that most patients were pleased with the overall outcome.

As in any shoulder arthroplasty, radiography becomes increasingly important to evaluate long-term results. For example, loosening of components can occur over time, which could eventually lead to failure. Both publications used X-ray for follow-up and determined that there was no loosening of components and no radiolucency discovered in 10 out of 11 patients. However, Hattrup and Cofield noted that anterior or superior (or both) glenohumeral subluxation occurred in all patients at an average of 76 months. This suggests that long-term arthroplasty results may be less promising than anticipated in paraplegic patients. Nevertheless, the fact remains that radiography is necessary in any patient receiving arthroplasty.

Overall outcomes are promising when viewed through the lens of the enormity of the challenge of this procedure in this population. As previously discussed, the increased load placed on the shoulders of those using wheelchairs or other assistive ambulatory devices leads to a high prevalence of chronic shoulder pathology. Nine of 11 patients had some form of rotator cuff tear diagnosed at the time of surgery. This can affect the type of surgery performed and the quality of the expected results. Postoperatively, patients are required to protect their shoulder for approximately 12 weeks, but the rigorous demands of daily life are likely to cause increased long-term complication rates. For example, as previously noted, Hattrup and Cofield noted eventual glenohumeral subluxation in all patients. That being said, both groups stated that they would continue to offer this procedure to appropriately selected patients due to improvement in function and relief of pain, despite the less than perfect results [25, 26].

Rotator Cuff Repair

Rotator cuff repair is the most thoroughly studied procedure in paraplegic population. Although the available research is largely limited to case reports and retrospective studies, general trends are apparent.

First, however, we must discuss some unique characteristics of this population and how they pertain to rotator cuff surgery. It is known that RCIs are more prevalent with increasing age due to the fact that most non-acute tears are degenerative in nature. The average age of paraplegic patients operated on was 57.7 years old [4, 11, 16, 24–27]. Simply based on the age of this cohort, one could predict worse outcomes. Furthermore, in the literature reviewed, the average time from spinal cord injury until surgery was 27.7 years [11, 16, 24–27]. Given what we know about the increased load and strain placed on the shoulders of wheelchair-bound patients, one could expect that RCIs would be more severe with time in this population. As Kerr et al. showed, wheelchair-bound patients have different tear characteristics with more anterosuperior patterns of injury [28].

The acuity of the tear also has been shown to have important prognostic value for patients undergoing repair in the general population. Only one study performed surgery in response to acute injury [4]. Not surprisingly, this study also showed the largest improvement in ASES score. This observation highlights the fact that long-standing or chronic tears are not as amenable to repair as acute tears. Thus, it may be advisable that adaptive athletes who suffer an acute injury have it repaired as soon as reasonably possible.

One of the first studies analyzing rotator cuff repair in the paraplegic population was done by Robinson et al. in 1993. Robinson et al. reported a case series on four spinal cord injury patients with impingement syndromes and incomplete or complete supraspinatus tears. All patients failed non-operative management. Postoperatively PROM was started at 3 days, active assisted range of motion at 2 weeks, and full active ROM at 3 weeks. Follow-up (5 weeks to 1 year) and outcome measures varied considerably. However, the authors reported overall success: "functional capacity that approached or equaled premorbid levels" and decreased pain complaints [27].

This study was followed by Goldstein et al. in 1997. Goldstein carried out another retrospective case series with five patients who underwent side-to-side rotator cuff repair between 1987 and 1997. The majority (4) had large full-thickness tears of the supraspinatus with atrophy of the supraspinatus without discrete history of trauma or acute event. One patient had a smaller supraspinatus tear without atrophy. After repair and acromioplasty, all patients' postoperative protocols varied widely. In general, patients were immobilized for at least 2 days and then restricted to PROM only for at least 6 weeks with some patients starting wheelchair propulsion at 3 weeks. At an 8–10-week follow-up, none of the large full-thickness tears had improved shoulder function or range of motion. The one patient with a smaller tear without atrophy had increased shoulder function, ROM, and decreased pain. These poor results were attributed to tobacco use, poor baseline ROM, and chronicity of the tears [11].

After Goldstein et al.'s largely discouraging results, another study by Popowitz et al. was conducted retrospectively on eight shoulders in five SCI patients. Each patient was given a trial of nonoperative management for 1–3 months. Then patients underwent rotator cuff repair via a mini-open deltoid-split incision. Postoperatively patients were limited to PROM for 6 weeks, then gradual active assisted, and at 8 weeks they began active ROM. They were followed for at least 1 year postoperatively. They found overall favorable results with reduced pain, improved transfers, and minimal loss of function. However, two of five patients required revision rotator cuff repairs after reinjury that was attributed to the weight-bearing nature of shoulders in this population [4]. Fattal et al. carried out a prospective study on 28 patients with spinal cord injury largely mirroring Goldstein et al.'s results with small decreases in FIM scores (2.3 points) and significant improvements in pain control [24].

The most recent studies on rotator cuff repairs in the wheelchair population were done by Jung et al. and Kerr et al. Jung et al. carried out a retrospective study on 13 paraplegic patients who failed conservative management and underwent rotator cuff repair between 1995 and 2011. The majority of tears were classified as massive intra-operatively (69%), and tears were repaired by a single surgeon either open or mini-open with acromioplasty and double mattress technique. Postoperatively PROM was fully started by day 3 and strengthening exercises started after brace removal at 2 months. Patients were advised against using the shoulder for propulsion for 6 months. Outcomes measured were the Constant score, ASES score, ROM, muscle strength, and imaging at 1 year to measure re-tear rate. Follow-up ranged from 13 to 71 months. At a 1-year follow-up, 14 out of 16 repaired tendons showed signs of recovery, while two showed evidence of re-tear. Overall, ASES scores, Constant scores, ROM, and muscle strength increased significantly [16]. Lastly, Kerr et al. carried out a retrospective case series analyzing full-thickness rotator cuff repairs in 46 wheelchair-dependent patients. All patients underwent surgery with a single surgeon and there was no discussion of technique. Postoperatively patients were hospitalized for 10 weeks, limited to PROM only for

6 weeks when manual wheelchair use was started again. Patients were encouraged to continue PT for 1 year. Patients were reevaluated with ultrasound at an unknown interval for integrity of repair. A high rate of repair failures (33%) was encountered, but in these patients Constant and ASES scores still had significant improvements. Overall, at a mean follow-up of 46 months, ASES and Constant scores increased significantly [28].

After careful analysis of the available research, it is apparent that rotator cuff repair in wheelchair-dependent patients who have failed non-operative management has good results. The applicability of these results to the adaptive athlete population will remain in question until further studies are completed. Most of the studies on rotator cuff repair showed improved pain control [16, 24, 27, 28]. Recent studies from 2015 also indicated improved functional scores even in patients with structural failure of their repairs. High rates of rotator cuff repair failure (12–33%) were encountered in both recent studies with relatively short follow-up periods [16, 28]. This is likely due to the high demand these patients place on their shoulders as well as the difficulty adhering to postoperative protocols when limited to the function of one upper extremity. In terms of postoperative protocols, there appears to be no consensus between authors with each study utilizing a different protocol.

Conclusion

In conclusion, current literature for surgical intervention in the adaptive athlete population is lacking. Further research is needed with higher-quality studies on rotator cuff repair, and additional research analyzing other upper extremity conditions in this population is essential. However, from the available research, it is apparent that adaptive athletes are candidates for rotator cuff repair with improvements in functional outcomes, ROM, strength, and pain. It is also apparent from the two available studies in adaptive athletes that shoulder arthroplasty results in improvement of functional outcomes but is associated with a high rate of complications.

Given the fact that surgical outcomes presented on RCI are increasingly positive in the wheelchair-bound population, it could also be anticipated that other areas of injury will respond satisfactorily to surgery. As we continue to gain more insight into this unique group of patients, so too will our ability to provide desirable results.

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8 Rehabilitation of the Adaptive Athlete

Ashley Lazas Puk and Arthur Jason De Luigi

Introduction

Although sports can be traced back thousands of years, the concept of adaptive sports has only begun to make traction in the last century. In 1888, the Sports Club for the Deaf was founded in Berlin [1], making it one of the first known organized sports programs for adaptive athletes. By 1940, the Paralympic Movement began taking off, and the first international competition took place in Stoke Mandeville, England [1]. Over the past decade, opportunities and awareness have broadened for athletes with disabilities. This has shown to be beneficial for these athletes on and off the court.

The Progression of the Adaptive Games to Present

The first Stoke Mandeville Games were held in 1948. There were only 16 athletes competing on teams at this time that came from only two rehabilitation facilities [1]. In 1951 there was as many as 126 athletes from 11 different hospitals that came out to participate in four different sports which included archery, netball, javelin, and snooker [1]. In 1952 participation internationally was started [1]. This was a result of the athletes participating in the events being there to represent their individual countries. The transition of the Stoke Mandeville Games allowed disabled athletes to be a part of a sporting movement instead of as a tool for medical purposes [1]. The Stoke Mandeville Games were held in the same location and venue as the Olympics in 1960 [1]. Since then, the Paralympic Games have been held every year and in the same city or country as the Olympics [2]. Then, 29 years later in 1989 the International Paralympic Committee (IPC) was formed [1]. In 2001 the IPC and International Olympic Committee started working together and decided that both the Olympics and Paralympics would be held in the same city, working under the committee and would be held in the same venues each year [1]. The number of athletes competing in the Paralympics continued to increase throughout the years, and in 1996 Paralympic Games there were 3500 athletes that represented 118 countries [2]. By 2008 there were a total of 3951 athletes from 148 different countries competing in the Beijing Paralympic Games [1]. Coming second to the Summer Olympics in popularity and viewership was now the Summer Paralympic Games [1]. During this event, worldwide, there were about 3.8 billion

A.L. Puk, ATC (✉)
MedStar Sports Medicine, Columbia, MD, USA
e-mail: Ashley.M.Lazas@medstar.net

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA
e-mail: ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_8

viewers [1]. This had increased the awareness of athletes with various disabilities to participate in various sporting events. Today, there are about 4000 Paralympic athletes in the 20 summer sports and 500 Paralympic athletes in the five winter sports every 4 years [3]. There are also about 4500–6000 disabled athletes that participate in organized sports in the United States [2].

Major Contributors to the Movement

There are several significant athletes that have shaped adaptive sports into where it is today. At the Stoke Mandeville Games in England in the 1940s, Sir Ludwig Guttmann, a neurologist, started encouraging spinal cord injury patients to participate in sports as a form of rehab [1]. Athlete Oscar Pistorius who is a South African double below-knee amputee has been a world record holder in Paralympic running events. He has also recently competed in the London Olympics as well as the Paralympic Games [1]. The case of Pistorius has done a great job worldwide at helping athletes with disabilities show that they are fully capable at succeeding at their sport. Tatyana McFadden was another important individual involved with the Paralympic Movement. Tatyana McFadden was a wheelchair athlete on the United States Paralympic team who was responsible for the passage of the "Fitness and Athletics Equity for Students with Disabilities Act" in Maryland in 2008 [1]. This law requires that schools allow students with disabilities to participate in physical education classes as well as athletic activities [4]. This law also allows students with disabilities to try out for school athletic teams [4].

The Benefits of Exercise and Competition for Adaptive Athletes

There are a number of benefits of exercise and competition for adaptive athletes. Participating in activities as well as competitions helps adaptive athletes focus more on the positive than the negative. It helps them look at the physical abilities that they do have rather than just focusing on their disability. Adaptive athletes who participate in exercise are shown to have an increase in self-esteem as well as a self-perceived quality of life. It was also shown in a study of 30 men with tetraplegia that the self-efficacy in sports is also shown to increase self-efficacy in activities of daily living [1]. In this study, the individuals stated that the special skills that were involved with their sport helped with the skills of daily living such as bed to chair transfers. Disabled athletes who participate in exercise and competition also tend to have an increase in body image and empowerment. Once a disabled athlete participates in a sport and/or competition, they have a continued motivation for involvement in sports. In 2010 Annekin et al. showed physical exercise to be a cause of increase in quality of life [1]. There was also a positive correlation between physical activity and rate of employment [1]. There has also been a correlation between participation in sports and positive mental health in disabled athletes. With so many benefits of exercise and competition for adaptive athletes, it is encouraged that these individuals participate in sports and get involved in the community.

Types of Disabilities Involved

There are a number of disabilities that are involved with the Paralympics and sports. The following disabilities are involved: amputees, spinal cord injury patients, cerebral palsy, wheelchair-bound athletes, and the visually impaired. There are other types of disabilities; however, these are the ones that we will focus on. There will be different types of injuries that are more prevalent in each of the disabilities. The types of injuries seen in each disability depend on the type of disability, the mechanics of the sports, and the equipment used [3].

The most common injuries seen differ between lower extremity and upper extremity amputees.

For lower extremity amputees, it is common to see fractures as a result of decreased proprioception from prostheses [3]. A number of these athletes also present with low back pain due to muscular imbalances. Lower extremity amputees are more susceptible to overuse injuries such as plantar fasciitis, Achilles tendinitis, and stress fractures in the intact limb [3]. Upper extremity amputees are more susceptible to cervical and thoracic spine injuries. This is a result of the imbalance and inequality of use between limbs.

Cerebral palsy athletes also have a high prevalence of fractures. Fractures may be seen as a result of decreased coordination which in turn is causing falls [3]. In cerebral palsy athletes it is common to see both upper and lower extremity injuries. In cerebral palsy athletes knee injuries are very common. They most commonly involve the patellofemoral joint and tight quadriceps and hamstrings [5]. Athletes with cerebral palsy also have an increased risk of metatarsalagia and ankle disabilities as a result of their ankle and foot deformities [5], such as equinus and pes valgus.

Spinal cord injury patients are the most common disability athletes that are using a wheelchair in athletics. Autonomic dysreflexia is a medical emergency that is usually seen in spinal cord injury athletes [5]. Spinal cord injury athletes also tend to have difficulty with thermoregulation [5]. In wheelchair athletes, the most common injuries were muscular injuries of the upper extremity. These injuries are a result of the high demand of the muscles in the upper extremity used in propulsion [5]. A majority of injuries in wheelchair athletes are overuse [2]. You will also commonly see bicipital tendinitis and rotator cuff impingement [5]. The median, ulnar, and radial nerves are the most commonly seen affected in overuse injuries [2]. Carpal tunnel syndrome is seen to be the most common overuse neuropathy in wheelchair users [2]. Ulnar neuropathy is the second most common neuropathy seen in the upper extremities of wheelchair athletes [2]. Muscular hypertrophy is commonly seen in wheelchair athletes which may increase their chances of developing nerve entrapments [2].

Visually impaired athletes have an increased risk of fractures as a result of falls from decreased proprioception and unseen obstacles (unfamiliar places) [3]. Lower extremity injuries are common due to abnormal gait and biomechanics. Ankle sprains and shin contusions appear to be the most common.

Rehabilitation and Care for Disabled Athletes

Many different medical professionals are involved in the progression of care for these athletes. The individuals taking part in the care of disabled athletes must be knowledgeable in both musculoskeletal injuries as well as neurorehabilitation [1]. These professionals include the following:

- Athletic trainers
- Physical therapists
- Physiatrists
- Orthopedic surgeons
- Family practitioners
- Pediatricians
- Prosthetists
- Orthotists

All of these professionals play an important role in the initial care and treatment of the athletes.

Athletes, in particular wheelchair athletes, are classified by their impairment and functional skills. Involved with the classification are physical therapists, occupational therapists, physicians, and technical representatives [2]. The team of health professionals completes both a neuromuscular and functional evaluation. The neuromuscular evaluation includes muscle strength, joint range of motion, posture, trunk balance, sensation, and spasticity [2]. The functional evaluation involves putting the athlete through various sport-specific activities [2].

When completing rehabilitation and treatment for disabled athletes, it is extremely important to discuss the treatment and expectations of the program between the athlete and the caregiver.

You should be able to set and discuss achievable goals of the program. There are a few differences between rehabilitation for disabled athletes versus non-disabled athletes. The injuries that disabled athletes experience may have greater consequences than those same injuries in non-disabled athletes. Musculoskeletal injuries will affect disabled athletes with their activities of daily living as well as their long-term quality of life [1]. When completing rehabilitation for both disabled and non-disabled athletes, it is important to discuss both exercises and treatment that will be completed in the clinic as well as exercises that need to be completed at home with caregivers. It is also important to discuss return to play protocols and set realistic goals for when the athlete will be able to return back to his/her sport. Each injury as well as disability has different rehabilitation goals. Each disability focuses on different musculature and mechanics.

Wheelchair athletes are more susceptible to shoulder injuries. As a result of propulsion, wheelchair athletes have strong anterior musculature and weak posterior musculature. For rehabilitation it is important to stretch anterior shoulder muscles and strengthen the muscles of the posterior capsule. Muscular imbalance is a main contributor to shoulder pain in wheelchair athletes. Shoulder abductors are stronger than both adductors and internal/external rotators [5]. Wheelchair athletes also have weak scapular stabilizers [5]. As far as rehabilitation, resting the shoulder in wheelchair athletes is impractical due to the high demand of the upper extremity for ambulation. Acute shoulder pain should be treated with ice and NSAIDs [5] as it would be in non-disabled athletes as well. Another treatment option may also include subacromial corticosteroid injections [5]. While completing rehab the physical therapists and athletic trainers should focus on stretching muscles of the anterior shoulder, strengthening adductors, internal/external rotators, and working on scapular stabilization [5].

For athletes with cerebral palsy, treatment should include physical therapy, medications, and bracing [5]. Rehabilitation should include stretching and a warm-up and cooldown. With cerebral palsy patients, benzodiazepines may help decrease muscle tone [5]. Bracing may also help to improve ambulation and contribute to decreasing muscle tone [5]. Amputee athletes should complete physical therapy that focuses on back and core stabilization as well as flexibility [5].

The treatment of injuries for blind athletes does not differ from non-disabled athletes [5]. Athletes who are visually impaired should take a tour of their rehabilitation facility prior to starting their treatment. This will help them become familiar with their environment which will help decrease their risk of injury and falls [5].

The rehabilitation goals and focus points differ depending on the disability and sport of the athlete. Treatment should focus on the specific demands of their specific sport.

Conclusion

Paralympic sports have come a long way since their start in 1888. Disabled athletes are participating in sports and competition worldwide. Athletes have been able to increase their quality of life as well as their mental and physical health by participating in exercise and sport. It is important to set realistic goals when rehabbing athletes depending on their specific disability and injury.

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Part III

Adaptive Sports

9 Adaptive Running

David Hryvniak, Jason Kirkbride,
and Christopher S. Karam

Introduction/History

Adaptive sports grew in the mid-twentieth century during the rehabilitation and reintegration of wounded veterans from World War II, the Korean War, and the Vietnam War back into society. One of the pioneers was neurologist Sir Ludwig Guttmann of the Stoke Mandeville Hospital in England, where he cared for many patients with spinal cord injuries. In 1948, while the Olympic Games were being held in London, he organized a sports competition for wheelchair athletes known as the 1st Annual Stoke Mandeville Games. These annual competitions laid the foundation for what would become the Paralympic Games [1]. The first International Stoke Mandeville Games were held in Rome, Italy in 1960 and featured 400 athletes from 23 countries. In 1976, people with limb deficiencies and visual impairment were included in the program, followed by those with cerebral palsy in 1980. In 1985, the term Paralympic was first used to describe the international competition that was considered "parallel with the Olympics." Currently, cities bid to host both the Olympics and Paralympics together in succession. The International Paralympic Committee (IPC) was formed in 1989 as the international organization governing elite sports for athletes with disabilities including physical and visual impairments. Together with the International Sports Federation for Persons with Intellectual Disability (INAS-FID) and Special Olympics, representing solely athletes with intellectual disability, the IPC acts as the representative body for adaptive sports.

With athletics being the cornerstone of the Summer Olympic Games every 4 years, adaptive track and field became one of the first adaptive sports introduced and one of the most popular. The sport offers a wide range of events, is open to male and female athletes in all impairment groups, and always attracts the largest number of spectators. The events on the Paralympic program include sprints, middle- and long-distance events, the marathon, field events, and the pentathlon. In addition, wheelchair road racing has become increasingly popular with larger and more competitive fields at most major marathons. The first wheelchair-borne marathon competitor competed in the 1975 Boston Marathon. In 2015, 40 years later, 50 push-rim wheelchair participants completed the 119th Boston Marathon [2].

D. Hryvniak, DO, CAQSM (✉)
Department of Physical Medicine and Rehabilitation, UVA Runner's Clinic, Team Physician UVA Athletics, University of Virginia, Charlottesville, VA 22903, USA
e-mail: djh3f@virginia.edu

J. Kirkbride, MD
Department of Physical Medicine and Rehabilitation, University of Virginia, Charlottesville, VA 22903, USA

C.S. Karam, MD
RA Pain Services, 15000 Midlantic Dr., Mount Laurel, NJ 08054, USA
e-mail: chris.karam@gmail.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_9

Disability Groups

To be eligible for adaptive competition in athletics, a person must have an impairment and disability which is evaluated to be severe enough to have an impact on the sport of athletics. The level of impairment is scored through a standardized process known as classification. According to the International Paralympic Committee, there are six disability groups that comprised of ten eligible impairment types including eight physical impairments as well as visual impairment and intellectual impairment [3]. The eight physical impairments include impaired muscle power, impaired passive range of motion, limb deficiency, ataxia, athetosis, hypertonia, short stature, and leg length difference. Descriptions of these impairments along with the aforementioned visual and intellectual impairments are seen in Table 9.1.

Classification

To ensure fair and equal competition, a classification system is used to group athletes into sport classes based on impairment and activity limitations (Table 9.2) [3]. The aim of classification in IPC athletics is to minimize the impact of eligible impairments on the outcome of competition. According to the IPC, athletes with impairments that have a similar impact on sport performance will generally compete in the same sport class. The system ensures that athletes do not succeed simply because they have an impairment that causes less of a disadvantage than their competitors but because of their skill, determination, tactics, fitness, and preparation. In order to be classified, the participant must submit a copy of the IPC Medical Diagnostic Form and all relevant documentation that is completed by their physician. For athletes competing in road races, such as the Boston Marathon, there may be different classification systems used (Table 9.3) [4].

Table 9.1 IPC eligible impairment types

Impaired muscle power	The muscles in the limbs or trunk are completely or partially paralyzed as a consequence of conditions such as spinal cord injury, polio, or spina bifida
Impaired passive range of movement	Range of movement in one or more joints is permanently reduced due to trauma, illness or congenital deficiency (e.g., conditions such as arthrogryposis or joint contracture resulting from trauma)
Limb deficiency	A total or partial absence of bones or joints, from birth, as a consequence of trauma (e.g., traumatic amputation) or illness (e.g., amputation due to cancer)
Ataxia	Lack of muscle coordination due to problems with the parts of the central nervous system that control movement and balance, typical of conditions such as traumatic brain injury and cerebral palsy
Athetosis	Repetitive and more or less continual involuntary movements caused by fluctuating muscle tone arising from problems in the central nervous system, typical of conditions such as cerebral palsy
Hypertonia	Abnormal increase in muscle tension with reduced ability of muscles to stretch and joint stiffness, slowness of movement, and poor postural adaptation and balance, due to problems in the central nervous system, typical of conditions such as cerebral palsy, traumatic brain injury, and stroke
Short stature	Standing height and limb length are reduced due to conditions such as achondroplasia and osteogenesis imperfecta
Leg length difference	Minimum of 7 cm leg length difference due to trauma, illness, or congenital conditions
Visual impairment	Vision is impacted by either an impairment of the eye structure, optical nerve/pathways or the part of the brain controlling vision (visual cortex)
Intellectual impairment	Limited intellectual functions and adaptive behavior, which must be diagnosed before the age of 18

Table 9.2 IPC sport classification track/running events

	Athletes with visual impairment
T11–T13	Athletes in these classes have a visual impairment, which is severe enough to impact on sport
	Athletes with intellectual impairment
T20	Athletes in this class have an intellectual impairment that impacts on the activities of running (400 m—marathon)
	Wheelchair racing
T32–34	These athletes compete in a wheelchair typically secondary to coordination impairments including hypertonia, ataxia, and athetosis (i.e., cerebral palsy, head injury, or stroke)
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
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
T53	Athletes typically have full function of the arms but no abdominal or lower spinal muscle activity (grade 0)
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
	Track running
T35–38	These athletes typically have coordination impairments including hypertonia, ataxia, and athetosis but are able to functionally run (i.e., cerebral palsy, head injury, or stroke)
T40–41	There are two classes depending on the body height of the athlete and the proportionality of the upper limbs. Athletes in classes T40 have a shorter stature than T41
T42	Athletes have a single above-knee amputation or impairments that are equivalent to an amputation above the knee
T43	Athletes have double below-knee amputations or impairments that are equivalent to a double below-knee amputations
T44	Athletes have a single below-knee amputation or impairments that are equivalent to a single below-knee amputation
T45	Athletes have double-arm amputations above or below the elbow or equivalent impairments
T46	Athletes have a single above- or below-elbow amputation or impairments that are equivalent to a single-arm amputation

Table 9.3 Boston Marathon wheelchair racing classifications

Quad class	
Class 1	Have functional elbow flexors and wrist dorsiflexors. Have no functional elbow extensors or wrist palmar flexors. May have shoulder weakness
Class 2	Have functional elbow flexors and extensors, wrist dorsiflexors, and palmar flexors Have functional pectoral muscles. May have finger flexors and extensors
Open class	
Class 3	Have normal or nearly normal upper-limb function. Have no abdominal muscle function. May have weak upper-spinal extension
Class 4	Have normal or nearly normal upper-limb function. Have no abdominal muscle function. May have weak upper-spinal extension

Equipment

Prostheses for Amputee Athletes

The prototypical prosthesis used by athletes for running and track and field is the "running blade (Fig. 9.1)." These are also known as energy, storing, and returning (ESR) prostheses or running-specific prostheses (RSP). Running prostheses are made from a carbon fiber polymer that is designed to store kinetic energy, similar to the way a spring functions. ESR prostheses are attached to the athlete using a socket, with liners and pads used to enhance fit and prevent skin breakdown. Sockets (Fig. 9.1) are created similarly for both athletic and non-athletic purposes, but sockets for athletes are commonly made of carbon fiber. This adds considerably to the cost but also improves durability and weight. ESR prostheses are designed for energy storage and propulsion. There are different designs to the ESR prostheses to allow for different distances and speeds of racing. There is no ankle joint or heel, making standing still with ESR prostheses difficult. Different surfaces can be attached to the bottom of the prosthesis for traction and improved wear. Athletes typically cut soles from running shoes and attach them to the prosthesis with glue

Fig. 9.1 The athlete in the figure is shown with his running blade attached to his custom-made socket. Photo courtesy of Lawall Prosthetics and Orthotics

or velcro. The Nike Sole is a shoe made specifically for attaching to running blades.

The energy cost of ambulation and running with a prosthesis is greater than an able-bodied athlete, which can vary based on speed, cardiovascular fitness, level of amputation, reason for amputation, and the properties of the prosthesis itself. The running-specific ESR prostheses can lower heart rate during exercise and lower the total energy cost to the athlete, when compared to a typical prosthesis. There is considerable debate about whether ESR prostheses offer an unfair advantage to disabled athletes during competition against able-bodied athletes and among other limb-deficient athletes. There have been multiple studies on the subject, yet no consensus has been reached. Some have concluded that there is no physiological advantage when compared with non-amputee athletes [5, 6], while others feel that the use of an ESR prostheses does provide an advantage [7–9]. Of note, there is some evidence to suggest the energy cost of an individual running with an ESR prosthesis is very similar to an able-bodied athlete. The length of the running blades has also been identified as a potential area for an unfair advantage among limb-deficient athletes [10, 11]. The IPC has set rules related to the length of prosthetic limbs used in competition by dictating a maximum allowable standing height (MASH) for athletes with prosthesis, commonly referred to as the MASH rule. These rules should be referenced when a limb-deficient athlete is being fitted for a prosthesis that will be used for competitive purposes.

It is also important for close follow-up of the limb-deficient athlete to ensure proper fit of the socket and prosthesis. Athletes can often develop skin breakdown, residual limb swelling, and pain secondary to a poorly fitted socket creating pressure points, poor circulation, and shear forces on the residual stump. Typical prostheses can last several years, but a change in fit and wear on the other components can often necessitate a revision or replacement.

Racing Wheelchairs

Racing wheelchairs consist of two larger rear wheels and a single wheel up front. The front wheel is smaller in diameter and extends well in front of the seat elongating the chair (Fig. 9.2). This provides improved stability and shock absorbance at the expense of maneuverability. The athlete is generally placed in a kneeling position, suspended in a sling, though a seated position in the chair is possible as well. Appropriate padding is necessary to prevent shear force and pressure to the weight-bearing surfaces. The athlete is fit tightly into the wheelchair to increase stability [12]. Similar to most sport wheelchairs, the wheels are cambered. They use pneumatic tires and aim to be very lightweight, most often with frames constructed of aluminum. The majority of wheelchairs tend to be custom fit; however, many athletes begin with a basic racing wheelchair that meets IPC regulations. When making custom adjustments, careful consideration should be paid to the IPC rules so that eligibility of the chair is retained (Table 9.4) [13]. Athletes are allowed one-hand rim per wheel, and they must have the ability for hand-operated

Fig. 9.2 Susannah Scaroni is shown demonstrating wheelchair propulsion mechanics. Photo courtesy of New York road runners. 2016 United Airlines half marathon

Table 9.4 IPC rules: racing wheelchair

Rule 159 Para 1	The wheelchair shall have at least two large wheels and one small wheel.
Rule 159 Para 2	No part of the body of the chair may extend forwards beyond the hub of the front wheel and be wider than the inside of the hubs of the two rear wheels. The maximum height from the ground of the main body of the chair shall be 50 cm.
Rule 159 Para 3	The maximum diameter of the large wheel including the inflated tyre shall not exceed 70 cm. The maximum diameter of the small wheel including the inflated tyre shall not exceed 50 cm.
Rule 159 Para 4	Only one plain, round hand rim is allowed for each large wheel. This rule may be waived for persons requiring a single arm drive chair, if so stated on their medical and Games identify cards.
Rule 159 Para 5	No mechanical gears or levers shall be allowed, that may be used to propel the chair.
Rule 159 Para 6	Only hand operated, mechanical steering devices will be allowed.
Rule 159 Para 7	In all races of 800 m or over, the athlete should be able to turn the front wheel(s) manually both to the left and the right.
Rule 159 Para 8	The use of mirrors is not permitted in track or road races.
Rule 159 Para 9	No part of the chair may protrude behind the vertical plane of the back edge of the rear tires.
Rule 159 Para 10	It will be the responsibility of the competitor to ensure the wheelchair conforms to all the above rules, and no event shall be delayed whilst a competitor makes adjustments to the athletes chair.
Rule 159 Para 11	Chairs will be measured in the Marshalling Area, and may not leave that area before the start of the event. Chairs that have been examined may be liable to re-examination before or after the event by the official in charge of the event.
Rule 159 Para 12	It shall be the responsibility, in the first instance, of the official conducting the event, to rule on the safety of the chair.
Rule 159 Para 13	Athletes must ensure that no part of their lower limbs can fall to the ground or track during the event.

mechanical steering and braking; however, there is not any gearing allowed. The rear wheels are limited to 70 cm diameter and the smaller front wheel 50 cm.

Wheelchair Propulsion Techniques

There are two propulsion techniques for wheelchair racers with retained upper extremity function. The first, called conventional technique or thumb technique, uses the hand in a finger-flexed position with the thumb extended. Athletes position themselves with a forward lean to allow the

Fig. 9.3 Aaron Pike is shown demonstrating wheelchair propulsion techniques. Photo courtesy of New York road runners. 2016 United Airlines half marathon

use of their trunk muscles and weight to generate force. Initial contact is made with the push rim contacting between the first joint and knuckle of the thumb. The shoulders are internally rotated and forearm pronated. Once contact is made, the dorsal surface of the 1st phalanx of the index and middle fingers makes contact with the push rim by supination of the forearm and "flick of the wrist." To protect against skin breakdown, heavy padding and taping are used over contact surfaces. The second technique is named the para-backhand technique and requires use of a specialized glove. The hand position starts with the fingers flexed and thumb pressed against the index finger. Initial contact occurs at the 1st phalanx on the dorsal surface of the index and middle finger. As the hand travels around the lateral surface of the push rim, contact moves to the base of the thumb and the 3rd phalanx of the index, middle, and ring fingers. Athletes are shown demonstrating these propulsion techniques in Figs. 9.2 and 9.3. A comparison of the two techniques revealed similar work per stroke; however, para-backhand had a longer push phase, which is ideal for endurance athletes as it requires a less explosive push stroke [14].

Injuries and Injury Prevention

Medical coverage of endurance races for able-bodied and adaptive athletes is similar, with some unique conditions the sports medicine physician should be aware of. Prevalent conditions include skin conditions, hyponatremia, heat illness, exercise-induced asthma, and overuse injuries. Providing education to participants regarding injury prevention is increasingly important in adaptive sports.

Skin problems are very common given the repeated contact with the wheelchair rim, tire, and locking mechanism. The upper arm and axilla region can also come into contact with the rim when trying to brake; therefore protection is critical. These can progress quickly, so routine skin checks are recommended. Often the camber of the wheelchair can be adjusted to allow more clearance of the axilla. Athletes should ensure they have proper padding and clothing to prevent skin breakdown, including on the upper arms. Gloves, taping, and callus formation can be successful at preventing hand skin breakdown in wheelchair athletes. Moist clothing should also be minimized. Given the positioning in the wheelchair, pressure sores can also be an issue. For long races, performing pressure relief techniques to unload the affected area and allow for circulation can be critical to preventing skin breakdown and formation of ulcers.

Overuse injuries, like in able-bodied athletes, typically arise from training errors, biomechanical problems or a combination of both. Common culprits include a recent change in training volume, an increase in training intensity, or a change in one's biomechanics or equipment, so all areas should be reviewed with the athlete. Overuse injuries in a limb-deficient athlete may be seen due to misaligned or poorly fit prostheses. In unilateral limb-deficient racer, the altered biomechanics of running and loading patterns with a prosthesis can put the contralateral limb at risk for osteoarthritis, stress fractures, plantar fasciitis, patellofemoral syndrome, and other overuse injuries commonly seen in runners.

The muscles most involved for wheelchair racing include the triceps, pectorals, deltoid, flexor carpi radialis, and the rotator cuff muscles and, as such, are usually most affected by overuse injuries [14]. Seating position is an important factor in the amount of muscle activation that occurs in propulsion. A lower seating position has been attributed with a smoother motion and more efficient pushing pattern [15]. The rotator cuff especially is at risk with these athletes as the biomechanical stress placed on these muscles is significant in wheelchair racing. Rotator cuff injury can be prevented through proper warm-up, proper mechanics, and a scapular stabilization and strengthening program. Typically these injuries can be managed conservatively; however, obtaining the necessary rest of the shoulder girdle musculature is difficult due to the need for continued daily use in a wheelchair-bound individual. Given the importance of the shoulder joint to mobility in a wheelchair athlete, surgical consultation should be considered early if not responding to typical conservative management.

Nerve entrapments, especially upper extremity, are a common condition in wheelchair athletes with rates greater than able-bodied athletes [16]. The most common sites are the median nerve at the wrist, the ulnar nerve at the wrist and elbow, and the distal radial sensory nerve. These often present with numbness, weakness, and pain in the hands and fingers in the distribution of the nerve affected. Physical examination, including a positive Tinel's sign at site of entrapment, and muscle weakness and/or atrophy, along with electrodiagnostics can be helpful to diagnose these nerve entrapments. It has been reported that while only 23% of wheelchair athletes present with clinical symptoms, approximately 64% of these athletes have some type of electrodiagnostic abnormality. One study found despite all the addition time training, wheelchair athletes have a similar or lower risk of median mononeuropathy than the general wheelchair-using population [17]. Conservative treatment for mild-moderate cases can include wrist splints, anti-inflammatories, and steroid injections; however, in the more severe cases often surgical management is required.

It has been shown that lower extremity injuries are more common in ambulatory athletes (visually impaired, amputee, cerebral palsy), while upper extremity injuries are more frequent in athletes who use a wheelchair [18]. Injury pattern studies based on the IPC functional classification system of athletes have produced similar results with wheelchair athletes most commonly sustaining upper extremity injuries, while limb-deficient runners most commonly sustain injuries to the residual limb, spine, or intact limbs. Athletes with cerebral palsy often suffer injuries involving the foot and knee, and visually impaired athletes most commonly suffer lower extremity injuries [19].

Special Considerations

In athletes with spinal cord injury (SCI), it is important to be aware of some unique considerations. These include autonomic dysreflexia and impaired thermoregulation.

Autonomic Dysreflexia/"Boosting"

Autonomic dysreflexia (AD) is an abnormal overreaction of the autonomic nervous system to some type of stimulation and should be considered a medical emergency. AD can develop in athletes with a neurologic level of injury at T6 or higher. A noxious stimulus below the level of injury, commonly bladder or bowel distension, can trigger symptoms. AD is characterized by sudden onset of hypertension (systolic blood pressure of at least 40 mm Hg over baseline), facial flushing, sweating, headache, and slowed heart rate. Keep in mind that individuals with a SCI often have a low baseline blood pressure; therefore, a blood pressure that may seem reasonable in another population could potentially be significantly elevated in the SCI population. AD can lead to seizures, cerebral hemorrhage, hyperthermia, cardiac arrhythmias, and pulmonary edema. The treatment of AD aims to identify and remove the noxious stimulus to therefore reduce the blood pressure. The athlete should remain upright, and all clothing and straps should be loosened or removed. The urinary catheter should be checked for kinks and flushed to ensure there is no obstruction, and the bowel may need to be dis-impacted. Blood pressure should be closely monitored and rechecked often. If there is not any noxious stimulus which can be readily identified, a short-acting antihypertensive is often given such as nitropaste or immediate release nifedipine. Males with SCI are often on PDE5 inhibitors and use should be determined before the use of nitrates. It is important for medical staff, coaches, and competitors to be familiar with the symptoms, triggers, and treatment of AD as this is unique to the SCI population.

Boosting is defined as the intentional induction of AD to gain a performance benefit. Boosting is considered doping and has been banned by the IPC due to the significant medical risks involved (Table 9.5) [20]. It has been shown to enhance performance over a 7.5 km race by nearly 10% [21]. Prevalence of boosting is high, with one study showing that more than 15% of athletes with SCI above T6 have voluntarily induced AD to improve their performance [22]. Athletes will typically induce AD by clamping a urinary catheter to cause bladder distension, overly tightening their leg straps, introducing electric shocks to their lower extremities/inguinal region, sitting on ball bearings or breaking a bone, most often a toe, prior to competition [23].

The IPC handbook considers AD to be present when the systolic blood pressure is greater than or equal to 180 mm Hg. The athlete's blood pressure

Table 9.5 IPC handbook, April 2009, IPC position statement on autonomic dysreflexia and boosting

1	Persons with cervical or high thoracic spinal injuries can suffer from an abnormal sympathetic reflex called Autonomic Dysreflexia. This reflex is caused by painful stimuli to the lower part of the body, particularly distension or irritation of the urinary bladder. The symptoms of dysreflexia are a rapid rise in blood pressure, headache, sweating, skin blotchiness, and gooseflesh. In serious cases, confusion, cerebral haemorrhage and even death can occur. This reflex may happen spontaneously or may be deliberately caused ("Boosting"). As this is a health hazard, the IPC forbids athletes to compete in a hazardous dysreflexic state.
2	An examination may be undertaken by physicians or paramedical staff appointed by the IPC and may be undertaken at any time including in the call up room or such other areas used by athletes for warm-up purposes prior to the competition. If an athlete fails to co-operate, the athlete will not be permitted to compete at that competition.
3	A hazardous dysreflexic state is considered to be present when the systolic blood pressure is 180 mm Hg or above.
4	An athlete with a systolic blood pressure of 180 mm Hg or above will be re-examined approximately 10 min after the first examination. If on the second examination the systolic blood pressure remains above 180 mm Hg the person in charge of the examination shall inform the Technical Delegate to withdraw the athlete from the particular competition in question.
5	Any deliberate attempt to induce Autonomic Dysreflexia is forbidden and will be reported to the Technical Delegate. The athlete will be disqualified from the particular competition regardless of the systolic blood pressure. In addition, a report on the deliberate attempt to induce Autonomic Dysreflexia will be provided to the IPC Legal and Ethical Committee for subsequent investigation in relation to the nonrespect of legal and ethical principles by the athlete and/or athlete support personnel.
6	If an athlete who has a spinal cord lesion at T6 and above is hypertensive, the athlete must produce medical evidence prior to competition supporting this. This medical evidence must outline the level of the athlete's resting blood pressure over a minimal period of 14 days preceding the competition, and what particular treatment the athlete is taking.
7	The issue of monitoring Autonomic Dysreflexia is primarily the responsibility of the athlete's NPC, especially its medical team. This responsibility includes: 7.1. Ensuring that their athlete(s) are not dysreflexic prior to entering the call-up area; 7.2. Ensuring that their athlete(s) are not using a mechanism which may cause or provoke dysreflexia; 7.3. Providing the authorised person who examines for autonomic dysreflexia, upon demand, with a list of resting blood pressures of their athletes concerned.

should be re-tested 10 min after the initial detection. If the blood pressure remains unchanged upon rechecking, or an athlete attempts to self induce AD, they will be excluded from competition. If an athlete with SCI at T6 or higher has hypertension, the pre-existing hypertension needs to be clearly clinically documented prior to competition, including documentation of the resting blood pressure over the preceding 14 days and the current treatments [24, 25].

Impaired Thermoregulation

Individuals with SCI are at much higher risk for heat illness due to the autonomic nervous system's impaired blood flow to the skin and ability to sweat distal to the level of injury. In addition, the relatively poor mechanical efficiency of upper limb exercise increases internal heat production [26]. Mild heat illness can present as heat cramps, while more severe heat illness can present as heat exhaustion or heat stroke. Heat stroke is a medical emergency with dangerously high core body temperatures (>104 °F), lack of thermoregulation with cessation of sweating, and concomitant mental status changes [27]. Treatment includes rapidly cooling an athlete by getting them out of the sun, applying ice water-soaked towels, and submerging the athlete in an ice water tub. Frequent mental status checks should be performed to monitor the patient's status along with measuring a core body temperature using a rectal thermometer. Oral hydration may be attempted, but frequently IV hydration with isotonic saline must be administered for fluid replacement. The athlete should be properly cooled prior to medical transport to a hospital. Athletes suffering from heat stroke can often experience a rebound hyperthermia after being cooled so they should be transported for advanced medical care and monitoring. Planning can be key to the medical director's prevention of heat-related emergencies. Weather predictions must be monitored for the week leading up to an event with Wet Bulb Globe (WBG) temperature being important factoring in temperature, humidity, and solar radiation. It is the medical director's responsibility to use this information to adequately inform the race director and participants about risk of activity and perhaps recommend canceling the event if WBG temperature exceeds 90 °F. Adequate pre-event hydration, acclimatization, and proper clothing are critical in preventing heat illness.

Conclusion

Adaptive sports, especially adaptive running and wheelchair racing, have been increasing in popularity and participation over the last century worldwide. The Paralympics and World Marathon Majors wheelchair races, including the Boston Marathon, are world-class athletic events with significant prize money and elite competition. It is important for the sports medicine team to be aware of the unique requirements regarding classification and participation in these events. Likewise, it is essential to understand the equipment, regulations, and distinctive biomechanical requirements of running prostheses and racing wheelchairs. Adaptive runners and wheelchair racers have many of the same sports medicine conditions arise as able-bodied athletes; however there are some unique circumstances that the sports medicine practitioner must be aware of. Education and prevention can be critical in preventing significant morbidity in care of adaptive athletes.

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10 Adaptive Cycling

Andrew H. Gordon and Arthur Jason De Luigi

Introduction

The realm of adaptive cycling is broad in scope in terms of both participants and adaptations. From handcycles, recumbent bicycles, traditional upright bicycles, and wheelchair systems, the cycle or wheelchair used must be designed with the patient's health and sport-specific needs in mind. There is a wide, diverse array of sports that support adaptive cyclist participation.

The Adaptive Sports Cycle and Wheelchair

The fleet of adaptive cycles comprises an array of different styles and components and should be equipped specific to the individual's physical challenge(s). Adaptive sports cycles may be classified by the sport for which they are designed to assist. There are indoor training rollers, everyday wheelchairs, competitive handcycles, tennis wheelchairs, recreation handcycles, racing wheelchairs, basketball wheelchairs, and wheelchairs for extreme sports, such as all-terrain wheelchairs for mountainous trails. Other sports that support adaptive cyclists even include archery, triathlon, and hunting.

A variety of para-athletes may use these, including athletes with limb deficiency due to amputation or congenital deformity, spinal cord injury (paraplegia and quadriplegia), hemiplegia due to stroke/brain injury, visually impaired athletes, and those with cerebral palsy/intellectual disability. In particular, adaptive athletes with visual impairments and/or those who are intellectually disabled may cycle with sighted, tandem cyclists who are trained in aiding the visually impaired and/or intellectually disabled cyclist.

Adaptive Cycling History and as a Paralympic Sport

Adaptive cycling has grown into an international phenomenon, enabling those with physical challenges to overcome them and integrate more seamless into society. The US Paralympic Cycling Team has athletes with limb deficiency, visual impairment, spinal cord injury, traumatic brain injury, cerebral palsy, and stroke [1]. Since the mid-1980s, adaptive handcycling has been organized as a competitive sport, become recognized by the International Paralympic Committee (IPC) as a form of paracycling in 1999, and finally part of the Paralympic Games

A.H. Gordon, MD, PhD (✉) • A.J. De Luigi, DO
Department of Rehabilitation Medicine,
Georgetown University School of Medicine,
Washington, DC, USA
e-mail: ahg623@gmail.com; ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_10

Table 10.1 Governed paracycling events

Road events	Track events
• Road race (men and women) • Individual time trial (men and women) • Handcycling team relay (men and women, mixed event)	• Tandem sprint (men and women) • Team sprint (men and women, mixed event) • 500 m time trial (men and women) or 1 km time trial (men and women) • Individual pursuit (men and women) • Scratch race (men and women)

Eight discrete events for both men and women compose the road and track races governed by the Union Cycliste Internationale (UCI). Road events include road races, individual time trials, and team relays. Formal track events are divided into tandem sprint, team sprint, time trial, individual pursuit, and scratch races

for the first time in 2004 in Athens [2]. Governance of paracycling was transferred from the IPC to Union Cycliste Internationale (UCI) in February of 2007, and the discipline separated into road and track races for a total of eight events (Table 10.1). The principal international competitions for adaptive cyclists include the World Championships, the Paralympic Games, and the World Cup [3].

The Paralympic Movement website (Paralympic.org) details the different classifications of para-athletes that may compete in adaptive cycling. The four main classes of adaptive cycling include handcycling, tricycling, bicycling, and tandem cycling depending on the degree and type of impairments. Of the ten eligible impairments for the Paralympics, eight qualify for inclusion in adaptive cycling: impaired muscle power, impaired passive range of movement, limb deficiency, leg length difference, athetosis, hypertonia, ataxia, and visual impairment. Those with intellectual impairment or short stature are excluded from competitive adaptive cycling.

Handcycling has five classes (H1–H5) (Table 10.2) with lower numbers indicative of more severe impairment(s). H1 athletes are tetraplegic (C6 or above) and generally have severe upper limb impairment with no ability to use their trunk or leg. H2 athletes are also tetraplegic (C7/C8) with severe athetosis, ataxia, and/or

Table 10.2 Classification of adaptive cyclists

Handcycling (H1–H5)	H1	Tetraplegic (C6 or above)
	H2	Tetraplegic (C7/C8)
	H3	T1–T10 injury
	H4	T11 down—reclining
	H5	T11 down—kneeling
Tricycling (T1–T2)	T1	Severe athetosis, ataxia, dystonia
	T2	Moderate athetosis, ataxia, dystonia
Bicycling (C1–C5)	C1	Grade 3 spasticity
	C2	Grade 2 spasticity
	C3	Less spasticity in upper limb (grade 1)
	C4	Grade 1 spasticity
	C5	Minimal impairment
Tandem cycling (B1–B3) (for visually impaired)	B1	No sight
	B2	Visual acuity 2/60, visual field <5°
	B3	Visual acuity between 2/60 and 6/60, 5° < visual field angle <20°

Each classification level of handcycling (H1–H5), tricycling (T1–T2), bicycling (C1–C5), and tandem cycling (B1–B3) is meant to better place each adaptive cyclist into brackets of competition with athletes of similar ability: (a) *handcyclists* are limited in their ability to use their trunk and/or lower extremities and (b) *tricyclists* are generally afflicted with coordination or balance deficits. An adaptive tricyclist may not be an amputee; (c) *bicyclists* are capable of riding a traditional upright bicycle; however, they need accommodations and/or adaptations secondary to a loss of muscle power or amputation. It is important to distinguish that C1–C4 cyclists may be single or double amputees, whereas a C5 cyclist may only be a single amputee; (d) *tandem cyclists* are visually impaired and ride with a sighted pilot cycler [4, 5]

dystonia. H3 athletes may have spinal cord lesions anywhere from T1–T10 (or equivalent injury) with limited trunk stability. H4 athletes will have impairment from T11 down, with normal or almost normal trunk stability, but be unable to kneel. Those competing in classes H1–H4 compete in a reclined position and compete on a recumbent handcycle, whereas H5 class athletes are paraplegics (T11 or below) and amputees who distinguish themselves from H1–H4 by being able to kneel and compete on a kneeling handcycle. Those competing in classes H1–H4 compete in a reclined position, whereas H5 competitors are capable of sitting on their knees and may use both their arm and trunk. Examples of H1–H4 athletes include those with spinal cord injury, cerebral palsy, or multiple sclerosis. H5 athletes may have leg amputation or congenital limb deficiency, paraplegia, or ataxia [4].

Tricycling has two classes (T1–T2) (Table 10.2), again with the lower number corresponding to a higher degree of impairment. Adaptive cyclists will use a tricycle if their coordination or balance is affected enough to require the tricycle for stability while riding. T1 tricyclists have severe athetosis, ataxia, or dystonia and generally with grade 3 spasticity or higher. T2 tricyclists have more moderate athetosis, ataxia, or dystonia with more fluent movements, grade 2 spasticity for hemiplegic and quadriplegic patients, and grade 3 spasticity for diplegic athletes.

Adaptive cyclists capable of riding a traditional upright bicycle will compete in one of five classes (C1–C5) (Table 10.2), once again with lower numbers corresponding to the highest degree of impairment. C1 cyclists have grade 3 spasticity in upper and/or lower limbs with poor strength in the trunk and/or extremities and can have single or double amputations. C2 cyclists have grade 2 spasticity throughout with greater lower limb involvement. C3 cyclists will have less spasticity in the upper limb (grade 1) versus the lower limb (grade 2) and with less athetosis, ataxia, or dystonia than C1 or C2 cyclists. C4 cyclists generally have grade 1 spasticity with the lower limb more involved and mild to moderate athetosis, ataxia, or dystonia. C5 cyclists have minimal impairment such as monoplegia spasticity with clear neurologic signs or single amputation. Classes C1–C4 may be amputees, whereas C5 athletes may not and have minimal impairments compared to the other classes. Examples of adaptive bicyclists include those with amputations, impaired muscle power or range of motion, and coordination deficits.

Tandem cyclists are typically visually impaired and ride with a sighted "pilot" cycler to their front. Visual impairments are classified from B1–B3 (Table 10.2), and they all typically compete together in the same event(s). B1 athletes have no sight. B2 athletes have the ability to recognize the shape of a hand up to visual acuity of 2/60 and/or visual field of less than 5°. B3 athletes have visual acuity of 2/60 up to 6/60 and/or visual field of more than 5° and less than 20°.

Adaptive Cycle Design and Technology

Initially designed for impaired military veterans after World War I to help them navigate more difficult terrain, the adaptive handcycle has evolved into a popular mode of cycle that allows adaptive cyclists to participate in cycling both recreationally and competitively. Four basic designs of handcycles exist: (1) an arm-crank add-on unit which attaches to the athlete's own wheelchair, (2) upright arm-crank units where the athlete is positioned similar to that of being in their own wheelchair, (3) cycles where athletes kneel with their torso straight up or leaning forward over the cranks, and (4) recumbent cycles in which the athlete lies supine while manning cranks above their chest. The main two designs used in the Paralympics are the latter "kneeling" and "recumbent" handcycles (Fig. 10.1). Road racing handcycles are usually three-wheeled with the front wheel chain controlled and operated by the adaptive athlete using their upper limb(s) and/or torso,

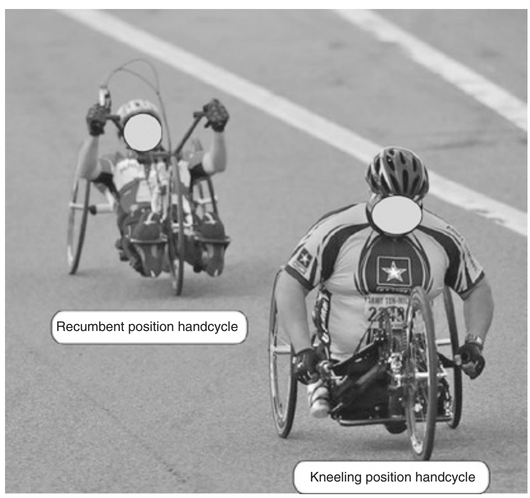

Fig. 10.1 Recumbent and kneeling position handcycles (adapted from Cooper and De Luigi, PM R 2014, S37)

contingent on their disability. Handcycles are more efficiently driven than standard pushrim wheelchairs, making them more ideal for road racing [2].

Tricycle and bicycle design and technology generally echo the standard design for able-bodied individuals with specific, limited adaptations (i.e., attachment for lower limb prosthesis to foot pedal, etc.). General considerations with regard to bicycle and tricycle design include the cyclist's body segments and bicycle/tricycle components, as well as the interface points of the body with the cycle (i.e., the perineum contact on the seat, the handgrip point on the handlebars, and shoe/pedal interface), which can all affect the upper and lower body reach of the cyclist. Changes in rider body position will directly affect aerodynamics and frontal surface area resistance. UCI regulations also only allow a standard diamond-shaped frame for upright bicycles during competition with various more aerodynamically designed frames outlawed [6].

A tandem cycle will generally take the form of a "two-seat" bicycle with the sighted "pilot" cycler seated in the back behind the visually impaired adaptive cyclist. Mechanical design of the tandem cycle must enable the riders to be as close as possible in order to optimize aerodynamics. The pilot controls steering, gear changing, and tactics, whereas the visually impaired cyclist must instantly react to cadence increases as well as changes from standing to seated positions on verbal cue. The visually impaired cyclist must also be able to remain calm and composed during sudden movements of the tandem cycle and changes in road slope or other race conditions [6].

Important variables when designing any adaptive cycle include saddle height, saddle setback, saddle tilt, the length of handlebar/hand control reach from the saddle, the handlebar height drop from the seat, crank length, and the saddle tube angle. Changes in cycle setup can influence trunk angle, which in turn can influence muscle recruitment and intermuscular dynamics throughout the body. Ideal adjustment of these variables in relation to one another will optimize power output for and race performance by the adaptive cyclist [6].

Prosthetic Design and Technology for Limb Deficient Adaptive Cyclists

Athletes with limb deficiency who participate in adaptive cycling will likewise be subject to an array of complications that can evolve from factors that include amputee biomechanics, athlete physiology, and prosthetic design. Once an adaptive athlete with an amputation is properly fitted to their cycle, the prosthetic(s) will require special adaptations in order to avoid complications involving such aforementioned factors. The cycling socket should be lightweight, optimize aerodynamics as well as energy storage and return, and allow for both range of motion and stability. The socket must also be customized for the type, intensity, and duration of activity that corresponds with the adaptive cyclist's typical competition speed(s). As of 2014, the UCI declared that all prosthetic devices used by competitors in paracycling competition must be formally approved for use [7].

Of paramount importance is whether the prosthetic is for the upper or lower extremity. Those who use upper extremity prosthetics will typically ride a standard upright bicycle but may also use a recumbent or kneeling handcycle. Athletes with upper extremity limb deficiency may need a specific terminal device capable of hand braking and/or upper extremity propulsion. Typically, though, those upper extremity amputees who use a handcycle will not need much else in terms of adaptations. Those with lower extremity limb deficiencies encompass a wider spectrum of options for riding with or without a lower limb prosthesis and may also ride any type of cycle. Athletes with lower extremity limb deficiency can still ride a standard upright bicycle. Transtibial amputees ride with prostheses more often than transfemoral amputees. The types of lower extremity prostheses used range from a standard foot or specific terminal device that can be clipped directly onto the foot pedal [8].

Adaptive cyclists with transtibial limb deficiencies (Fig. 10.2a) benefit from suspension systems that cross the knee in order to best enable maximal knee flexion while cycling. Typical suction/gel sleeve systems are commonly replaced

Fig. 10.2 (**a**) Transtibial amputee on standard upright bicycle. (**b**) Transfemoral amputee on standard upright bicycle (adapted from Fergason and Harsch, Care of the Combat Amputee, 2009)

with pin-and-lock mechanisms, but the athlete may still elect to use a more traditional gel sleeve that is already flexed and able to maintain suction for a good seal. It is also critical to keep the posterior rim of the socket low enough so that it does not cut into the athlete's leg while in more flexed positions [8, 9].

Athletes with transfemoral deficiency (Fig. 10.2b) need their cycle seat adapted to allow proper space between the ischium and the seat so that the leg may clear the seat while cycling, and the cyclist may be comfortable while seated for an extended period. Knees that allow free motion are typically easier for athletes with transfemoral deficiency to manage while riding [8, 9].

Foot stiffness of both transtibial and transfemoral prostheses may be increased in order to maximize energy of the cycling motion. This is not without trade-off, as this is excessively stiff for walking. Additional control and stability may be achieved by attaching the prosthetic foot directly to the foot pedal and/or biking shoe in order to avoid unintentional displacement or doffing of the prosthesis during cycling. Athletes with unilateral transtibial deficiency also demonstrate more asymmetry with pedaling than completely able-bodied cyclists, resulting in more force applied and work done by those limb deficiencies [8, 9].

Sports Wheelchair Technology

Briefly, as other adaptive wheelchair sports are more comprehensively covered in another chapter, adaptive sports wheelchairs are generally classified by the sport for which they are designed to assist. Sports wheelchair design, similar to cycles, must optimally fit the athlete, minimize weight, offer significant support and stability, be easily maneuverable, and simultaneously be sport specific [10]. Frames for these chairs utilize aluminum, titanium, or composites. Elite athletes will favor composite materials as, while they are typically more expensive and require more labor to fabricate, they can offer more significant stability than their aluminum or titanium counterparts.

Injuries and Medical Concerns

As adaptive cycling is so diverse, so is the array of medical complications and injuries they may sustain. Injuries often mirror those seen commonly in particular conditions, such common diagnoses encountered in more traditional rehabilitation diagnoses such as spinal cord injury or stroke.

Autonomic Syndromes, Environment, and Boosting

Patients with spinal cord injuries are unable to maintain and regulate normal body temperature above the T8 level [11]. Therefore athletes with paralysis at the T8 level or above may be at increased risk for heat exhaustion or heat stroke during competition. Those with spinal cord injuries at the T6 level or above are at risk for autonomic dysreflexia (AD) as well as orthostatic hypotension [11]. Some adaptive cyclists may be also excessively sensitive to heat, cold, or altitude, particularly cyclists with higher level spinal cord injuries whose autonomic function can be dysregulated.

There has been concern over the years for doping by para-athletes to self-induce AD ("boosting") that could in turn enhance para-athlete performance. AD is a very potent sympathetic reflex that is caused by a massive release of noradrenaline [12]. Boosting is often induced by overdistending the bladder via ingestion of a large amount of fluid before competing [13]. While this practice improves performance, it also can increase blood pressure substantially, which could be dangerous to the athlete's health. Deliberate attempts to boost by adaptive athletes are expressly prohibited by the IPC and can lead to disqualification and investigation if detected [12]. Only recently has testing for AD in handcycling competitions been implemented, and they have yet to yield a positive test nor have any adaptive handcyclist been disqualified. This potentially offers hope that testing can serve as a reliable deterrent to AD [12, 14].

Musculoskeletal, Neurologic, and Pain Syndromes

Adaptive cyclists, whether they have paralysis, hemiplegia, or limb deficiency, share many of the same musculoskeletal and neurologic complications as those who do not participate in adaptive sports. In the upper extremity, adaptive cyclists may sustain injuries to the palms of their hands, as well as their wrist, shoulder, and elbow joints. Pain can also occur in the spine and pelvic region and the lower extremities such as the hip, knee, leg, ankle, and foot. There may also be an increased risk of compartment syndrome in the extremities of adaptive cyclists, especially if there is undue pressure from a prosthetic component or if they have difficulty moving their extremities leading to increased intra-compartmental pressures and pain. If compartment syndrome is suspected, compartment pressure testing should be done as soon as possible.

Upper extremity neuropathy such as carpal tunnel syndrome or ulnar neuropathy occurs in as many as 2/3 of spinal cord patients, so even higher vigilance must be paid to adaptive cyclists in these regards. Myelopathy from syringomyelia, thoracic outlet syndrome, and spasticity are also very common in spinal cord injury patients and can easily be seen in adaptive cyclists [11].

It is very frequent for persons with SCI to have upper extremity issues as 70% of chronic SCI patients will report pain in their upper limbs. Tetraplegic athletes will be at higher risk for upper extremity pain than paraplegics. As such, it is important to have a high index of suspicion for common causes of upper extremity pain in adaptive athletes. The shoulder will be most commonly affected as it is used as a weight bearing joint in wheelchair athletes. Tendinitis, (subacromial) bursitis, rotator cuff injury, capsulitis, myofascial pain, and cervical radiculopathy are common reasons for upper extremity pain in these cases.

Heterotopic ossification (HO) often develops in those with SCI or other sedentary paraplegic/quadriplegic conditions, and likewise such adaptive athletes may have HO-related pain. Treatments include physical therapy, modalities, dry needling, and oral medications including acetaminophen, NSAIDs, oral steroids, and bisphosphonates (particularly for HO). Injectable treatments also include steroids, prolotherapy, viscosupplements, and platelet-rich plasma. Physical therapy should focus on range of motion, scapular stabilization, and rotator cuff strengthening to promote stable, balanced shoulder and upper extremity movements so that while cycling the adaptive athlete has optimal posture and kinesiology. Functional electrical stimulation may be used to help conditioning and muscle bulk/strength as well. Stress or pathologic fracture is also a risk as such adaptive athletes may have decreased bone density in the setting of impaired ambulation.

For those patients with cervical spinal cord lesions, tendon transfer or nerve grafting procedures may be necessary to restore more optimal function to the upper extremity in order to allow better ability to control a handcycle. Upper extremity neuropathy such as carpal tunnel syndrome or ulnar neuropathy occurs in as many as 2/3 of spinal cord patients, so even higher vigilance must be paid to adaptive cyclists in these regards. Myelopathy from syringomyelia, thoracic outlet syndrome, and spasticity are also very common in spinal cord injury patients and can easily be seen in adaptive cyclists [11].

Neuropathic pain, characterized more by burning, tingling, or shocking pain, can also arise in such athletes and should be treated first with neuropathic agents such as gabapentin or pregabalin, as well as tricyclics such as nortriptyline or amitriptyline. One may also try treating neuropathic pain with anticonvulsants such as carbamazepine or even topicals such as capsaicin, lidocaine, or diclofenac. Complex regional pain syndrome (CRPS) can also be seen in adaptive cyclists if they have a specific focal injury result in nerve damage [11].

Pudendal nerve entrapment has been more frequently seen in upright bicyclists and those who use a stationary bike for exercise. They are increased risk due to chronic perineal microtrauma resulting in inflammation and/or fibrosis in the pudendal canal and sacrotuberous/sacrospinous ligaments where the pudendal nerve lies [15]. Treatments for pudendal nerve entrapment and nerve irritation include adjusting and/or changing the saddle as well as rider position, prescription of neuropathic agents as listed above, and image-guided pudendal nerve blocks with steroid and/or anesthetic.

Gastrointestinal/Genitourinary

Adaptive cyclists with spinal cord injury will commonly present with neurogenic bowel and bladder and already have interventions in place (i.e., suprapubic catheter, bowel program) for which adaptations need to be made to the athlete's cycle in order to accommodate them. Neurogenic bowel and/or bladder dysfunction may occur by dysregulation and/or injury to both central and peripheral neural pathways that can affect innervation to the gastrointestinal tract and/or bladder [11].

Unfortunately, there exists controversy with regarding to "boosting" in Paralympic athletes in which adaptive cyclists intentionally overdistend their bladder to activate autonomic dysreflexia. This doping method increases the sympathetic response just prior to competition, resulting in a noradrenaline surge. There has yet to be an adaptive handcyclist who has had a positive test for this as per IPC testing guidelines as previously discussed [12, 14].

Cardiopulmonary

Sedentary or impaired individuals are commonly at higher risk of deep vein thrombosis or pulmonary embolism and this is of particular concern in paraplegic/tetraplegic athletes. Adaptive cyclists can also have (exercise induced) asthma requiring intermittent or chronic treatments including inhalers and nebulizers, as well as rescue inhalers available. Amputees are known to have higher energy consumption than able-bodied athletes, so cardiopulmonary demand in such cyclists can be higher [11]. Arrhythmias, coronary artery disease, and heart failure can be seen in adaptive cyclists with associated physical decompensation. Adaptive cyclists may also have peripheral vascular disease resulting in claudication and decreased functionality of their extremities [11].

Dermatologic and Skin Conditions

Careful attention should be paid to areas where an adaptive cyclist may place excess pressure or friction while cycling leading to weight bearing and/or overuse injuries. The gluteal and buttock regions could be unusually susceptible to pressure ulcers or friction abrasions depending on positioning and stress while cycling. The upper and lower extremities could also be susceptible to blisters and friction abrasion. Areas of increased pressure on the body of an adaptive cyclist can function as niduses for skin breakdown, infection, and systemic disease. Particularly with regard to athletes with paraplegia or tetraplegia from spinal cord injury, vigilance with regard to skin care is essential in these athletes. The adaptive cyclist may or may not have sensation depending on whether they have a spinal cord lesion and the location. This decreased sensation could decrease awareness of the athlete with regard to skin breakdown. Lacerations, pressure ulcers, rashes, and callous formation could all lead to skin breakdown in the sensate or insensate athlete, particularly at the seat of the cycle where there would be prolonged pressure on bony prominences (i.e., the ischial tuberosity) where the athlete sits [11].

Dermatologic conditions are also of heightened importance in limb deficient athletes: folliculitis, boils, abscesses, verrucous hyperplasia, lichenification, tinea corporis and cruris, epidermoid cysts, contact/allergic dermatitis, and excessive sweating can lead to skin lesions, infection, and further systemic complications if not controlled [11].

In each of these cases, traditional wound healing measures would include cleaning and irrigating the affected area (usually with isotonic saline), applying the appropriate dressing, and taking antibiotics if there is suspicion for bacterial infection. Vitamin supplements (multivitamin, zinc, vitamin C, copper, arginine) may be taken for severe cases. Also, if the wound fails to heal by conservative measures, a wound vacuum and/or surgical intervention may be necessary [11].

Endocrine

Diabetes or thyroid disease could affect neurologic function and/or cause skin breakdown in adaptive cyclists. Adaptive cyclists with decreased mobility could have decreased bone density and osteoporosis. In these regards, vitamin D and calcium levels should be monitored and appropriate patients sent for bone density scans to assess the degree of bone loss. Adaptive cyclists with traumatic brain injury may also suffer from hypopituitarism/hypogonadism which in turn can promote osteoporosis [16].

Psychological Factors

Handcyclists with spinal cord injury, amputations, traumatic brain injury, or other impairment are already facing psychological challenges intrinsically associated with their impairment(s). Engaging in adaptive handcycling can help such athletes cope in these regards. Simultaneously, they are also susceptible to any range of depression, anxiety, (post-traumatic) stress, or other emotional dilemma (possibly pre-existing prior to their impairment) that could require counseling or management with psychotropic medications. A psychiatrist should be consulted for any adaptive cyclist with suicidal ideation, psychotic features, or lack of response to multiple psychotropic medications. Also adaptive cyclists may require intervention by a sports psychologist just as an able-bodied athlete would [11].

Conclusion

Adaptive cycling is a Paralympic sport that is now globally embraced, experiencing rising popularity with more participating athletes and formal international competitions. The athletic population seen in adaptive cycling is quite diverse, as exemplified by the array of physical challenges and complications seen in these athletes, as well as the complexity of adaptations/equipment needed for them. The emergence of adaptive cycling has allowed para-athletic men, women, and children to find a new avenue for athletic activity capable of improving their physical, emotional, and cognitive well-being while simultaneously allowing participation in various levels of organized competition. More research and study is needed to better understand the requirements of these athletes and how best to provide them with the best supports possible.

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Adaptive Golf: History, Rules and Equipment Modifications, and Sport-Specific Injuries

11

Mayur J. Amin, Joseph A. Sclafani, and Arthur De Luigi

The Game of Golf: A Brief History

Modern golf evolved out of primitive ball and stick games that date back to the 1400s in Scotland, England. These Scottish ancestral roots penetrate to the etymology of the word "golf" itself, which is a Scottish interpretation of the Dutch word for club (Kolf) [1]. In its infancy, golf was scrutinized by the English government and was temporarily outlawed in the early 1500s when the sport was deemed a conflict to civilian military training. After these prohibitory laws were lifted in the late 1500s, the popularity of the sport within the country began to skyrocket [2]. Soon, even Scottish royalty began to partake in the sport. Mary, the Queen of Scot's became an avid golfer and oftentimes enlisted students referred to as cadets to carry her clubs [3]. It is believed that this is the origin of the word "caddy."

Although increasing numbers of Scottish citizens were participating in the sport during the 1600s, early golf course layouts lacked organization, and there were no official rules. Many of the ensuing rules and amendments to the early game were parsed out at the Old Course located within the St. Andrews Links in Scotland. For example, the original Old Course contained 22 holes that were eventually restructured to 18 holes when the members of the club felt that the first four and last four holes on the course were too short and should be combined [4, 5]. Numerous articles including the oldest surviving rules of golf are preserved in the National Library of Scotland. These documents, drafted in 1744, detail foundational rules of the sport including "You are not to change the ball which you strike off the tee" and "If a ball be stop'd by any person, horse, dog, or anything else, the ball so stop'd must be play'd where it lyes [6]."

Golf gradually began to disseminate to other parts of the world after gaining increasing popularity throughout Europe during the 1800s. Historically, it was a game of the middle to upper class due to the expense of early equipment. The first generations of golf balls were handmade by a skilled craftsman from leather sewn around duck feathers. A seasoned worker was able to manufacture five balls per day on average which necessitated an expensive pricing model to regain costs from the consumer [7]. Economic barriers to the lower classes were deconstructed as equipment manufacturing processes evolved over the early to middle 1800s. The first featherless golf ball was constructed out of gutta-percha, the rubberlike sap of the gutta tree, in 1848. This approach was significantly less expensive than

M.J. Amin, MD (✉) • J.A. Sclafani, MD
MedStar Georgetown University Hospital/National Rehabilitation Network, Washington, DC, USA
e-mail: maamin99@gmail.com

A. De Luigi, DO
Medstar Georgetown University Hospital/National Rehabilitation Network, Washington, DC, USA

Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA
e-mail: ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_11

hand sewing individual golf balls, and as a result people of all socioeconomic backgrounds could better afford to participate in the game [2, 7].

Golf arrived in Northeastern USA during the late eighteenth century, but the popularity of the game was initially oppressed by the Civil War during the nineteenth century. The first golf course on American soil was built in 1888 by John Reid, a transplanted Scotsman. This course consisted of three holes in a cow pasture located in Yonkers, New York. A group of men that frequently played this course established the St. Andrews Club of Yonkers, the first golf club in America [2]. Popularity continued to blossom and disseminate to other major cities over the upcoming years, and by 1894 there was a movement to form an organizing body to oversee the game within the United States. The United States Golf Association (USGA) was formed in 1894 following a meeting of delegates from six US regional golf clubs in New York City after the US National Amateur Championships [5]. Over 200 new local golf clubs had joined the USGA by 1910, and there were over 1100 affiliations by 1932. The expansion of golf throughout the United States was halted during the Great Depression and World War II but quickly resumed in the post-war era. Currently there are over 10,000 USGA-affiliated golf clubs, and 50% of golf courses worldwide are located within the United States [8]. Nearly 27 million people participated in recreational golf in the United States alone during 2014 [9].

Adaptive Golf: Legislation and Community Perception

The Americans with Disability Act (ADA) was enacted in 1990 to afford protections against discrimination and provide reasonable public accommodations to the over 57 million individuals with disabilities in the United States [10]. The National Center on Accessibility (NCA), in cooperation with Clemson University, began to advocate for appropriate development of golf course infrastructure and programs to facilitate golfers with disabilities shortly after the passage of the ADA. As part of this campaign, the NCA compiled a census of survey results which found 10% of people with a disability currently play golf and 35% of those not currently playing are interested in learning to play [11]. Golf course owners and operators were also surveyed as part of this campaign. While the majority of the 83 facility respondents were aware of the ADA, they did not explicitly understand how it applied to their facilities. Greater than 90% desired more education directed toward making their facilities more accessible without impairing course conditions for recreational golfers of all abilities.

This desire for increased education was shared by the interviewed cohort of golfers with disabilities. Multiple survey responses detailed that negative experiences oftentimes stemmed from golf establishment concerns over damage to greens by mobility devices and slowing of the pace of play. As a result, many golfers with a disability recommended more research be done investigating the impact of mobility devices on putting green turf conditions as well as standard provision of single rider carts by more golf facilities. These concerns were addressed by an extensive investigation of how different modalities of mobility, ranging from an athletic shoe to a single rider golf cart, impacted golf course turf indentation. The worst case scenario in this study, a narrow and rigid standard wheelchair tire rolling on a putting green with high soil moisture, created a much less than expected indentation of 0.07 in. A specialized wheelchair with wide pneumatic tires caused even less impact on the same surface with an indentation of 0.04 in. Although single rider carts were not available for prolonged data collection, initial results suggest that they did not cause significant surface depression when used on the putting green surface. Altogether, the results of this study indicate that within 30 min of all types of wheel traffic, the putting green turf had completely rebounded, and rutting was no longer detectable [12].

Adaptive Golf: Clubs and Events

Numerous adaptive golf clubs have been established to support and advocate for disabled individuals interested in participating in the game of golf. The following is a brief overview of some currently active major organizations.

The National Amputee Golf Association [13]

Started regionally by a WW2 veteran who sustained a below knee amputation along with other veterans that sustained similar injuries. This association conveys a message of ability and self-pride to participating members. By 1954, the group was incorporated into and supported by the PGA as well as the USGA. Currently, there are 2000 members in the United States and 200 additional players from 17 other countries combined. The National Amputee Golf Association established "The First Swing" program to promote the game of golf to the disabled community and rehabilitation professionals. The First Swing Seminars emphasize accessibility issues, introduction of adaptive equipment, instruction on beginning golf techniques, and education about resources within the community to assist in the development of an adaptive golf program.

The National Alliance for Accessible Golf [14]

An organization that is endorsed and supported through grants from the USGA to further the community of adaptive golf. The National Alliance for Accessible Golf has developed the GAIN (Golf: Accessible and Inclusive Networks) program to utilize golf as a vehicle to integrate individuals with a disability into their community. Over 8000 GAIN grants have been distributed across 21 states since 2010 to individuals with physical and mental disabilities.

The Adaptive Golf Association [15]

Another excellent organization, founded in 1997, that promotes ADA compliance across municipal golf courses and the game of golf to individuals with physical disabilities. The Adaptive Golf Association organizes multidisciplinary clinics and workshops with physical therapists, occupational therapists, and PGA professionals.

Training and Lead-Up Activities

Golf is a unique competitive sport in that the least talented amateur is able to compete on the same course as the most accomplished, highly trained professional athletes. The skill disparity between amateur golfers is accounted for by an official handicap system maintained by the USGA [16]. As part of this system, recreational golfers with a high handicap may utilize easier tee box locations throughout the course. Additionally, there is a deduction of a predetermined number of strokes from their overall score in an effort to level the playing field against more highly skilled (or able) golfers. This structure encourages participants to fine-tune their abilities after a round of golf so they have a better chance of scoring better relative to their handicap in subsequent rounds.

Although golfers of all skill levels are able to participate in the game, it is recommended the code of conduct and fundamentals of golf be learned prior to setting out on a regulation course [17]. This will ensure the participant is using proper techniques to maximize swing efficiency, avoid unnecessary injury, and maintain an acceptable pace of play. Many adaptive organizations listed above offer "learn to golf" clinics designed to teach the basics of the game to disabled individuals [13–15]. Techniques learned in these clinics can then be applied at a golf practice facility which typically offers a driving range (long-distance practice), chipping greens (short game practice), and putting greens. Once the novice golfer feels comfortable in the practice environment, they can progress to playing on an executive golf course, which is ideal for those playing at a beginning level. These courses, comprised of many par 3s and short par 4s, are designed for golfers who struggle with the length and intensity of a standard golf course. After several rounds on an executive layout and multiple practice sessions at the driving range, a novice golfer is typically ready to begin play on a standard or championship length golf course.

Rules/Modifications of the Game

The USGA has subdivided disabled golfers into five groups: blind golfers, amputee golfers, golfers requiring canes or crutches, golfers requiring wheelchairs, and golfers with intellectual disabilities [18]. Each of these groups has a set of permissible modifications to allow the disabled golfer to impartially compete with an able-bodied individual or a golfer with another type of disability. Rule modifications by disability are discussed below.

Blind Golfers [19]

Per USGA modifications, blind golfers may employ the assistance of a "coach." A coach is defined as an individual who assists a blind golfer in addressing the ball and with alignment prior to the stroke. Each player may utilize only one coach at a time during competition. The golfer may also ask for and receive strategic advice from the coach. The coach can take on the role of a caddie as well; however, if there is a separate caddie, the coach is not allowed to carry or handle the clubs except for helping the player take his stance and aligning himself prior to the stroke.

Amputee Golfers [20]

With regard to amputee golfers, the USGA rules and regulations discuss the status of prosthetic devices. An artificial leg or arm can be used to accommodate a medical condition in a player with a legitimate medical reason to use the device. However, the governing body of each event must deem that the artificial limb does not give the player an unfair advantage over other players. With regard to artificial arms, clubs used by players must conform to the USGA regulations; however, an attachment can be fitted to the grip or shaft to assist the player to hold the club. Players who are unsure of their device should raise the issue with the event's governing body as soon as possible.

Golfers Requiring Canes or Crutches [21]

Golfers using assistive devices require a modification of official regulations pertaining to "taking the stance" while addressing the ball. In a player using an assistive device, taking the stance entails placing the device and their feet in a position to make a stroke. The assistive device is considered to be an extension of the player's stance under the modifications to the official USGA rules.

In contrast to a conventional golfer, a player utilizing an assistive device is allowed to bend or break branches of a tree or bush when initiating their stance. Disabled golfers, however, cannot use their assistive device to clear golf course hazards once they have initiated their stance. This population is allowed to receive physical assistance for positioning an assistive device prior to initiation of a stroke.

Golfers Requiring Wheelchairs [22]

The USGA rules and regulations state that wheelchair golfers can employ both a caddie and an aide, as long as the aide does not carry or handle the player's clubs nor does the aide give advice to the golfer.

Rules for dropping and re-dropping after striking a ball out of bounds have been modified for wheelchair golfers. Under these rules, it states that the ball must be dropped by the player, and he must either stand or sit upright while holding the ball at shoulder height and arm's length. If a ball is dropped by anyone other than the player, the player will be penalized one stroke. With regard to ball placement, conventional rules and regulations state only the competing player may place the ball. However, given the physical limitations of the player in a wheelchair, this rule has been modified to allow ball placement by the player, his partner, or another person authorized by the player.

Golfers with Intellectual Disabilities [23]

Golfers with intellectual disabilities will have different requirements based upon the severity of their disability. Some may require supervision on the course to assist in some or all aspects of play, while others may only need support on an as-needed basis from an "overseer." The overseer is an individual employed by the event's governing body to assist in upholding conduct during the competition. These officials are not specifically assigned to a certain player but are available to assist any player requiring assistance during the competition.

Additionally, a "supervisor" role has been created within the rules and modifications for golfers with intellectual disabilities. The supervisor is an individual who assists a golfer with their play and compliance with official rules and golf etiquette. A player may request and receive advice from their supervisor with regard to any of these categories. Each player may utilize only one supervisor at any time to be in compliance with the USGA rules and modifications. However, an intellectually challenged competitor may use both a supervisor and a caddie during play as long as the supervisor does not handle or carry the player's clubs at any time.

Adaptive Equipment

Along with modifications to the rules of the golf, there are physical assistive devices that facilitate an even playing field between disabled and able-bodied golfers. A variety of available devices are discussed below.

Golfers with Loss of Upper Limb Function [24]

There are numerous conditions leading to impaired use of an upper extremity or a weakened grip. Some of these include hemiplegia post stroke, amputation, arthritis, spinal cord injury, head injury, and peripheral neuropathies. One option available to golfers with impairment in a unilateral upper extremity is to play one-handed. There are a multitude of adaptive components available to facilitate club handling for such golfers including gripping aids, oversize grips, cushioned grips, shock absorbers, and gloves (Table 11.1). Lightweight, flexible shafts are also advantageous in generating more club head speed, resulting in longer shot distance.

Golfers with Loss of Lower Limb Function [24]

Players with loss of limb function in one or both lower extremities may choose to play from a seated position (Table 11.2). There are several prosthetic devices engineered to improve

Table 11.1 Various upper limb assistive devices [25–27]

Device	Description	Intended user
Powerglove	Golf glove with loop to secure club grip to glove that ensures a firm hold throughout the swing	Golfers with arthritis or weak grip
Eagle Claw	Golf grip aid which assists with developing and maintaining grip strength and swing accuracy	Golfers affected by arthritis or illnesses that affect grip strength and limit golfing ability
Golf TD	Single piece grip that stores energy on the backswing that helps improve club head speed	Golfers with right or left hand unilateral absence (requires minimal secondhand assistance)
Golf Pro	Flexible grip duplicates the wrist action required for a smooth, controlled swing	Golfers with right or left hand unilateral absence. Intended for more advanced golfers
Tampa Bay Dynamic Recreation Elbow	Replaces the majority of components in a standard trans-humeral prosthesis with a dynamic energy storing system	Golfers with unilateral very short to long trans-humeral absences. Short sport prosthesis is required

Table 11.2 List of mobility devices for disabled golfers [28–30]

Device	Description	Intended user
ParaGolfer	All-terrain mobility device that lifts players from sitting to standing position allowing eye-level play with other golfers	Wheelchair-bound or players with limited mobility
Golf Express	Single rider golf cart allows golfers to play from a seated or supported standing position	Golfers with limited mobility who can support their own weight
SoloRider	Single rider golf cart with single-hand use capability and sit to supported stand function	Golfers requiring mobility aid due to chronic or abrupt disability

mobility and swing mechanics in the amputee population. Rotation is aided through torque absorbers fixed to either below knee or above knee prosthesis. Additionally, new prosthetic foot designs aid in rotation and shock absorption and adapt easily to uneven terrain. Having the prosthetist work closely with the golfer and their golf instructor during the process of making the prosthetic device is encouraged. It is also helpful to work with a prosthetist that understands the biomechanical properties of each stage of a proper golf swing.

Miscellaneous

A wide variety of other adaptive equipment has been designed to assist disabled individuals with various aspects of the game (Table 11.3).

Table 11.3 List of miscellaneous equipment for disabled golfers [31–35]

Device	Description	Intended user
Chromax Golf ball	High visibility golf ball allows for more accurate putting and ball identification	Golfers with impaired or decreased vision
Backsaver System+	Allows placement and pickup of ball and tee peg without bending	Golfers with injury making bending difficult as well as those with less fine motor in hands
Joe's Original Backtee	Attachment for any grip that allows ball and tee placement without bending	Golfers with injury making bending difficult as well as those with less fine motor in hands
Ball Pickup	Attachment for any golf putter grip that allows retrieval of ball without bending	Golfers with injury that have difficulty with bending
Adapta-Club	Specially fit golf clubs for disabled golfers. Hinged design allows clubs to lie in a flat position	All golfers with disability based upon personal comfort

Golf Injuries and Rehabilitation

In the United States, there are more than 26 million golfers, of which about six million are avid golfers in that they play 25 or more rounds of golf per year. As the population ages, golf will increase as a popular leisure time activity because it allows a variety of individuals to play simultaneously [36]. Along with this increase in the number of golfers, there will be an expected rise in golf-related injuries. The golfer with a disability is neither immune nor prone to injury during practice or play. In 1996, it was reported that more than 36,000 individuals presented to the emergency room in the United States for treatment of golf-related injuries [37]. In the United States golf injuries in male participants mostly involve the lower back, whereas female golfers are more likely to have problems with the elbow, wrist, or shoulder [38, 39]. To understand the cause of golf-related injuries, one must first look into the mechanics of the golf swing. The golf swing involves a high-torque lateral bending movement, for which the anatomy is poorly suited [40]. Additionally, many beginning golfers use maladaptive swing techniques that adversely affect the kinetic forces on the trunk, shoulders, and legs. Poor technique and overuse can lead to injury; most amateur golfers have injuries due to poor technique, while professional golfers are more likely to have injury caused by repetition and frequent practice [41]. In this section we will discuss the types of golf injuries along with appropriate medical and rehabilitation management options for the injured golfer.

Low Back Injury

The low back is the most frequently injured area of the body in both amateur and professional golfers. Appreciation of golf swing mechanics along with the biomechanics of the spine is essential to understand golf-related low back injuries. The modern golf swing involves a large shoulder rotation with a semi-constricted turn in the hips to build torque in the muscles of the lower back and shoulder [42]. This technique is advocated by many teaching professionals but leads to greater angular displacement of the spine and is suspected of being a major source of injury for professional and amateur golfers. Biomechanical models have demonstrated that the golf swing significantly increases lateral bending, shear, compression, and torsional forces at the L3 and L4 motion segment [43].

The etiology of lower back pain can be multifactorial and may appear as significant medical, orthopedic, or neurologic problems. After successful treatment of the acute injury, it is essential for the golfer to strengthen and improve flexibility in the spine, legs, and shoulders. Improving the function of the latissimus dorsi, hamstrings, and anterior and posterior trunk muscles which stabilize the spine is critical to protect against future injuries or flare-ups of low back pain related to the initial injury [44]. Warming up with gradual stretching before the round and a cooldown phase after play are also helpful to reduce injury. Other considerations include using special equipment such as a long putter to reduce thoracolumbar kyphosis and pushing a cart rather than pulling to decrease torsional forces about the spine [42].

Shoulder Injuries

Overall, there is a relatively low incidence of shoulder injury in golfers compared to other sports. Overuse or high volume repetition with training or practice leads to soft tissue inflammation which may cause shoulder injuries, especially in older golfers. Senior golfers are more prone to shoulder pain due to bursitis or rotator cuff injury secondary to impaired circulation or musculotendinous deconditioning. In younger golfers (less than 35 years of age), joint laxity or repetitive high velocity swing can cause excessive microtrauma to the rotator cuff mechanism [42].

The shoulder of the non-dominant or lead arm is more frequently involved in golf-related injuries. The lead arm is at maximal adduction during backswing, which can cause pain secondary to acromioclavicular joint pathology or impingement syndrome at the top of the backswing. Pain in the posterior aspect of the shoulder can be secondary to posterior capsulitis or a tight posterior joint capsule. During the high velocity downswing, weak scapular muscles can lead to instability and secondary interscapular pain [42].

Accurate diagnosis is the key to the rehabilitation of shoulder injuries. Identification of pathologies resulting from restricted motion versus joint laxity can help to design a treatment algorithm and determine if operative or non-operative treatment is best indicated. Strengthening of key muscle groups involved in the golf swing including the rhomboids, rotator cuff, latissimus dorsi, and triceps is important for good shoulder health and should be incorporated into the individual's home exercise program both before and after injury. Golf swing modifications can also be made depending on the diagnosed pathology. A player with a rotator cuff impingement may be advised to flatten their swing, whereas a golfer with acromioclavicular joint arthritis may be recommended a more upright swing [45].

Elbow, Wrist and Hand Injuries

Although medial epicondylitis is most commonly referred to as "golfer's elbow," numerous studies have shown that lateral epicondylitis, "tennis elbow," is more likely to occur [46]. Epicondylitis may develop due to repetition from increased practice or weak forearm muscles and is more likely to affect women than men [38].

Fractures of the hook of the hamate commonly present as pain at the ulnar aspect of the palm of a golfer's hand. They are more likely to occur in the hand grasping the end of the club (left hand in a right-handed golfer) and may occur secondary to trauma. Palpation of dorsoulnar aspect of the wrist or direct pressure applied over the hamate may reproduce the pain. Radiographs may appear to be inconclusive and often a CT scan is required to make the diagnosis. Treatment of hook of the hamate fractures often involves surgery to remove the fractured hook as conservative therapy with immobilization often fail to heal the fracture [47]. To reduce the pain at impact, bicycle gloves which pad the thenar eminence may be beneficial.

Excessive cocking of the wrist on the backswing, rapid deviation of the wrist at impact, and sudden deceleration at impact when the club strikes a rock, root, or turf are potential causes of wrist and hand tendinitis in the lead hand during the golf swing. Female golfers are particularly susceptible to extensor pollicis longus tendinitis (De Quervain's tenosynovitis), extensor carpi ulnaris tendinitis, or flexor carpi radialis and flexor carpi ulnaris tendinitis. The incidence of wrist tendinitis can be increased with "strong" grip position where the hands are rotated clockwise on the handle of the club [42].

After identifying the correct diagnosis and completing appropriate clinical treatment, modification of the golf swing and equipment can prevent further injury to the wrist and hand. Adoption of a flat-planed, elliptical swing and restriction of wrist motion drastically decrease direct force placed on the hand and wrist. Club grips should be replaced every 40–50 rounds and can also be purchased in an oversized version which is larger and softer. Additionally, golf clubs should be fitted properly so that the butt end of the club handle extends approximately 1 in. beyond the hypothenar eminence of the trailing hand. In general, clubs that are too short place pressure on the hook of the hamate bone and increase the risk of fracture.

Lower Limb Injuries

Although hip injuries during golf play are uncommon, hip pain is common among older players and is often related to arthritis. Strains, sprains, and inflammation of the trochanteric bursa, iliotibial band, or tensor fascia lata can also occur, especially in female golfers. These ailments are best treated with non-operative interventions including development of a strength and conditioning program [48].

Rotational forces about the knees during the golf swing, walking the course, or repetitive knee flexion to pick up a ball or tee can all lead to injuries [49]. A regular program of strengthening and flexibility exercises for the hip rotators, quadriceps, hamstrings, and gastrocnemius along with adoption of an athletic knee flexion posture during the swing motion is advised for most golfers experiencing hip or knee pain [42].

Head and Neck Injuries

Golf-related injuries to the head and neck are rare; however, they have been infrequently reported. Most injuries are related to blunt trauma from being struck by a ball. However, golfers may report posterior lower neck and upper back pain while carrying a golf bag on one shoulder. In this case it may be advised to use both shoulder straps to reduce retraction and downward rotation force on a single scapula or periscapular muscle group. Another option is implementing a golf pushcart, which as previously stated, places less torque on the spine [42].

Conclusion/Summary

The widespread popularity of golf has transcended across all populations within the community, including groups with physical and mental disabilities. There are several adaptive devices and organizations available to accommodate golfers with disabilities. Additionally, modifications to the official rules of golf have been sanctioned by governing committees to facilitate individuals with various physical and mental disabilities. In some cases, individuals with disabilities are more susceptible to golf-related injuries than the non-disabled population. These injuries can be minimized with proper equipment fitting and appropriate pre-competition training.

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Wheelchair Basketball

12

Rajat Mathur, Patrick Martone, and Arthur Jason De Luigi

Introduction

Wheelchair basketball is one of the most popular sports for wheelchair users in North America, and it has been played since the end of World War II [1]. Many young veterans who were paralyzed or confined to wheelchair as a result from the injury suffered, while overseas were left frustrated, depressed, and lacked an outlet for energy [2]. Wheelchair basketball eventually spread across many different veteran's administration (VA) hospitals across the United States [3]. The sport eventually crossed the borders into Canada and Europe. In 1949, Tim Nugent was the founder of National Wheelchair Basketball Association. Initially, the tournaments were only open to veterans with spinal cord injury or paraplegia, but now the participation is open to civilians [4] (see Fig. 12.1).

R. Mathur, MD (✉) • A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA
e-mail: rickyrajat@gmail.com; ajweege@yahoo.com

P. Martone, DO
Department of Physical Medicine and Rehabilitation, MedStar Georgetown University Hospital/National Rehabilitation Hospital, Washington, DC, USA
e-mail: pmartone41@gmail.com

Disability Groups and Classifications

The majority of wheelchair athletes have suffered from spinal cord injuries. A smaller percentage of athletes also suffer from limb deficiency, amputations, or neurologic disorders such as cerebral palsy, spina bifida, post-polio syndrome, and traumatic brain injury. Regardless of the type of disability, all players in wheelchair basketball are organized by their functional ability or "volume of action." For example, a player with a T12 complete spinal cord injury and a player with a bilateral hip disarticulation may be grouped into the same class. Classifications are not based solely on the same type of injury but rather the athlete's functional ability to support their trunk and utilize their upper extremities [5] (see Fig. 12.2).

This classification system is used in an effort to ensure that the outcomes of games are determined by a player's athletic ability and not by the level of a player's impairment. The classification system is divided in categories from 1 to 4.5 with half point increments. In determining the difference between a class 1 and 4.5, players are viewed based upon their function, most specifically, their ability to stabilize and more especially their trunk, which is referred to as a player's "volume of action" [6] (see Fig. 12.3).

The "volume of action" (Table 12.1) of a player is determined by his ability to voluntarily move in any direction and return to an upright seated position. The planes at which this is

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_12

Fig. 12.1 Nationals team pic

Fig. 12.2 Harsh defense

examined are the vertical plane, or rotation; the forward plane, a bending forward of the trunk toward the feet; and the sideways plane, leaning the trunk to the left or to the right. Based upon a player's ability to perform these movements with control, they are placed into a classification as follows:

Like in basketball, wheelchair basketball also utilizes five members per team on the court at a time. However, each player's class is tallied together, so at no point can the total points of the five players on the court exceed 14 points. For example, three class 4 players, one class 2 and one class 1 player may be on this court because this would be equivalent to 14 points. Therefore the classification system emphasizes one's skill level and capabilities instead of their disabilities [7].

Other rules which apply to wheelchair basketball include:

Fig. 12.3 Harsh defense2

Table 12.1 Volume of action

Class	Volume of action
1.0	No active trunk movement in rotation, little to no controlled trunk movement in forward plane, no controlled trunk movement in sideways plane, and when unbalanced must rely on the arms to return to upright position
2.0	Has active upper trunk rotation, but no lower trunk rotation, partially controlled trunk movements in the forward plane, no controlled trunk movements in the sideways plane
3.0	Complete trunk movement in the vertical plane, complete trunk movement in the forward plane, no controlled movement in the sideways plane
4.0	Complete trunk movement in the vertical plane, forward plane and to one side but difficulty with controlled movement to the other side
4.5	Complete trunk movement in the vertical plane, forward plane and movement to both sides

1. The player has a permanent severe leg disability or paralysis of the lower extremities. The eligible player may be an individual who would benefit from wheelchair basketball participation or someone who may be denied the chance to participate in basketball if it were not for the wheelchair adaption.
2. A wheelchair must be in use.
3. The chair is thought to be a part of the player. General rules of contact in regular basketball such as charging or blocking apply to wheelchair basketball.
4. Dribble: The player who is in possession of the ball may not push it more than twice in succession with one or both hands in either direction without tapping the ball to the floor. A traveling violation is constituted when the player takes more than two consecutive pushes. However, the player may wheel the chair and bounce the ball simultaneously just as an able-bodied player runs and bounces the ball simultaneously in a regular basketball [7].

Equipment

Wheelchairs used in basketball are designed specifically for the sport. This is to enhance the speed, endurance, stability, agility, and ruggedness. Many variables can be modified to meet these needs.

Camber is the angle between the wheels and the vertical position. In other words, camber allows for the distance between the top and the bottom of the main wheels to be different due to a change in the wheel's angle [8]. Increasing the wheel camber allows for easier and faster maneuverability of the chair and can help prevent contact between wheelchairs during a match [9] (see Fig. 12.4).

Other adaptations which are used to increase the performance of the wheelchair include the position of the footrest, castor wheels, and seat height. Positioning of the feet underneath the seat has been shown to improve maneuverability.

Fig. 12.4 Dee.Harsh

Fig. 12.5 Avery.Tony

Castor wheels are small wheels at the front and the rear of the chair. Castor wheels at the front of the chair allow for greater stability during high speed turns, while rear castor wheels aid in preventing tipping of the chair [8]. Seat height can also be utilized to allow for full elbow extension which can maximize a player's push angle [10]. Wheelchair modifications are performed based on the needs of the athlete, the athlete's disability level, impaired hand function, and amount of trunk support required (see Fig. 12.5).

Elite wheelchair athletes will typically have extremely well designed and efficient wheelchairs to get them around the basketball court. However, the cost of these can be prohibitive for some athletes. The design of the athlete's wheelchair can also affect the wheelchair athlete's injury profile. Higher quality competitive wheelchairs that are low weight and have movable components which have less friction will improve the efficiency of athletes. Using a better designed wheelchair can help reduce the risks of injuries.

Medical Conditions and Injuries

While wheelchair basketball players are skilled and talented athletes, their circumstances make them more susceptible to certain types of injuries. From the use of repetitive muscle to propel a wheelchair to the effects on the cardiovascular and endocrine systems which are inherent in the spinal cord and other neurologic conditions, wheelchair basketball players are faced with a unique set of medical conditions.

Musculoskeletal Injuries

Propulsion of a wheelchair (Table 12.2) requires the use and force of multiple muscle groups in a coordinated effort. Wheelchair basketball further complicates this matter as it requires quick and repetitive motions to keep up with the pace of the game. Wheelchair propulsion can be divided into two phases: the push phase, in which active contact and propulsion of the wheels are taking place, and the recovery phase, which is characterized by arm deceleration and lifting the arm to its return [11].

During the push phase, muscles which are actively used include the anterior deltoid, pectoralis major, supraspinatus, infraspinatus, serratus anterior, and biceps brachii. At the late recovery phase, the muscle is required to slow the extension of the arm. This action is performed by the anterior deltoid, pectoralis major, and biceps brachii. The action is then followed by these same muscles contributing to rapid shoulder flexion.

Table 12.2 Muscles used for wheelchair propulsion [12]

Muscle	Origin	Insertion	Action
Pectoralis major	Clavicular head: anterior border of the medial half of the clavicle Sternocostal head: anterior surface of the sternum, the superior six costal cartilages, and the aponeurosis of the external oblique muscle	Lateral lip of the bicipital groove of the humerus	Clavicular head: flexes the humerus Sternocostal head: extends the humerus As a whole, adducts and medially rotates the humerus. It also draws the scapula anteriorly and inferiorly
Pectoralis minor	Third to fifth ribs, near their costal cartilages	Medial border and superior surface of the coracoid process of the scapula	Stabilizes the scapula by drawing it inferiorly and anteriorly against the thoracic wall, raises ribs in inspiration
Rhomboid major	Spinous processes of the T2–T5 vertebrae	Medial border of the scapula, inferior to the insertion of the rhomboid minor muscle	Retracts the scapula and rotates it to depress the glenoid cavity. It also fixes the scapula to the thoracic wall
Rhomboid minor	Nuchal ligaments and spinous processes of C7–T1	Medial border of the scapula, superior to the insertion of the rhomboid major muscle	Retracts and rotates the scapula, fixes the scapula to the thoracic wall
Serratus anterior	Fleshy slips from the outer surface of upper eight or nine ribs	Coastal aspect of medial margin of the scapula	Protracts and stabilizes the scapula, assists in upward rotation
Infraspinatus	Infraspinous fossa of the scapula	Middle facet of greater tubercle of the humerus	Lateral rotation of the arm and stabilizes the humerus
Supraspinatus	Supraspinous fossa of scapula	Superior facet of greater tubercle of humerus	Abduction of the arm and stabilizes the humerus; see part on controversy of action
Subscapularis	Subscapular fossa	Lesser tubercle of the humerus	Internally (medially) rotates the humerus, stabilizes the shoulder
Teres minor	Lateral border of the scapula	Inferior facet of greater tubercle of the humerus	Laterally rotates the arm, stabilizes the humerus
Lower trapezius	Spinous processes of the remaining thoracic vertebrae (T4–T12)	Scapular spine base	Scapular depression

The serratus anterior also contributes to shoulder stability by holding the medial border of the scapula to the rib cage. The infraspinatus and supraspinatus are required to maintain external rotation of the arm [13].

During the recovery phase activity of the middle/posterior deltoid, the supraspinatus, subscapularis, middle trapezius, and triceps brachii are required. The triceps function to decelerate the arm and initiate extension of the shoulder, while the middle/posterior deltoid and supraspinatus provide elevation of the arm. The trapezius provides scapula retraction during arm return. One must keep in mind, however, that depending on a player's level of injury, the activity and utilization of certain muscle groups will vary [14].

Musculoskeletal injuries are the most frequent medical problem with competitive wheelchair basketball. Wheelchair basketball players are at increased risk for routine musculoskeletal injuries such as straining a muscle when compared to those of able-bodied athletes. Wheelchair athletes are at an increased risk for overuse injuries. The overuse injuries are distributed quite differently because of the use of wheelchair propulsion. The shoulder complex is the most commonly injured area, and the wrist is the second most common. The shoulder injuries could be unilateral or bilateral in location and are often considered overuse injuries but could be traumatic. A history of shoulder pain is reported in wheelchair basketball athletes, with an increasing prevalence in the proportion to the amount of trunk and upper extremity disability.

Shoulder impingement syndrome is by far the most common injury. Bicipital and rotator cuff tendinopathy in addition to tears are also common. Paraplegics are especially susceptible to rotator cuff tendinopathy, because they are more prone to internal rotation of the shoulder due to the force of the pectoralis major [15]. The excessive internal rotation of the shoulder places the greater tuberosity under the acromion process, making impingement syndromes more likely. Furthermore, wheelchair athletes often have a protracted scapula position due to an underlying scapular dyskinesis resulting in a decreased subacromial space. The humeral head is then elevated as a result of the imbalance in muscle strength [16].

The scapular stabilizer muscles are the primary muscles of wheelchair propulsion. Preventive measures, strengthening, and conditioning are all beneficial to all wheelchair athletes. A rehabilitation treatment approach includes a modification of strengthening programs, proprioceptive techniques, and flexibility exercises.

Inspection is usually normal for primary external impingement but can reveal positive Hawkins and Neer exam findings, rotator cuff weakness, lateralization of the scapula, a flattened anterior deltoid, and a mild scapular winging in cases of secondary external impingement [17].

Palpation may reveal tenderness in the region of the rotator cuff tendons. Patients with internal impingement may demonstrate tenderness in the posterior-superior GH joint. Active and passive range of motion may be reduced in external impingement and may elicit a painful arc of shoulder motion. Athletes with internal impingement will demonstrate increased external rotation and decreased internal rotation with end-range pain. Other findings may reveal weakness of the cuff musculature and instability. Special tests that can reproduce pain include the Neer impingement sign and the Hawkins sign [18]. Instability testing may be positive in secondary external impingement and internal impingement. X-ray may help evaluate acromial morphology, AC joint arthrosis, and os acromiale and rule out calcific tendinopathy and lesions of the humeral head or subluxation. Musculoskeletal ultrasound examination is a diagnostic tool to obtain dynamic real-time anatomic information about the severity and etiology of shoulder pathology [19]. Magnetic resonance imaging can reveal partial- and full-thickness rotator cuff tendon injuries with high sensitivity [20]. A rehabilitation regimen should include allowing the injured tissue to heal, minimizing the effects of immobility from pain, and then slowly increasing the strength of the rotator cuff and scapular musculature.

Nonsteroidal anti-inflammatory medications, cold modalities, ultrasound, and, occasionally, a steroid injection may be used to help treat the pain and inflammation. Surgery should be considered only after a 3- to 6-month period of targeted rehabilitation [21].

Nerve Injuries

Nerve entrapments are commonly seen in wheelchair basketball athletes when compared to ambulatory athletes. The incidence of median nerve entrapment at the wrist is the most common, followed by ulnar neuropathy at the wrist, elbow, and radial neuropathy. Shoulder dyskinesis and imbalance may also lead to suprascapular neuropathy.

Carpal tunnel syndrome, or median nerve compression deep to the transverse retinacular ligament, is a common complaint found in wheelchair users and especially basketball wheelchair athletes. The increased force and repetition of repeatedly pushing a wheelchair makes one more susceptible to median nerve pathology at the wrist [22]. Players often present with paresthesias in the hand but sparing the thenar eminence, as well as pain in the wrist, arm, and hand [23].

Physical exam findings to help identify carpal tunnel syndrome include Phalen's sign, reproduction of symptoms with wrist flexion, as well as Tinel's sign, percussion over the nerve to elicit symptoms. Electrodiagnostic testing can be used to help confirm the diagnosis. Treatment can include conservative measures such as volar splinting, range of motion exercises, and corticosteroid injections. The use of properly fitting gloves has been shown to decrease neuropathy at the wrists. If conservative measures fail, surgical options may be required [24].

Ulnar neuropathy is another common nerve injury found in wheelchair athletes, with injury at the wrist being most common, followed by injury at the forearm [25]. Pathology of the ulnar nerve at the wrist usually occurs in the Guyon canal, an area which includes the volar carpal ligament, pisiform, hook of hamate, and the transverse retinacular ligament. Entrapment of the ulnar nerve at the elbow is known as cubital tunnel syndrome. Players can present with symptoms of sensory disturbance in the hypothenar region as well as intrinsic hand weakness. They may also have medial elbow pain in cases of ulnar pathology at the elbow. Exam findings can include intrinsic hand weakness as well as atrophy of the hypothenar region. EMG can be used to help confirm diagnosis and the site of the lesion. Treatments include activity modification, avoiding full flexion at the elbow in cases of cubital tunnel syndrome as well as changing of hand position for pathology at the wrist, as well as splinting techniques [25].

Radial nerve injuries frequently present as posterior interosseous nerve (PIN) syndrome. This is because the radial nerve splits into the radial sensory nerve and posterior interosseous nerve proximal to the supinator muscle. PIN syndrome is a pure motor syndrome and players can present with fingers which lack the ability to extend. The supinator is the most common site of entrapment at the arcade of Frohse. EMG can be used to confirm the diagnosis. Conservative therapy, such as with NSAID use and stretching, should be considered, and if no improvement, surgical consult should be obtained [25].

Suprascapular neuropathy is sometimes present in players due to excessive overhead activities. Players present with dull or chronic pain in the shoulder region and may also have decreased strength in shoulder abduction and external rotation. The suprascapular nerve is most commonly entrapped in the suprascapular notch and the spinoglenoid notch. Suprascapular neuropathy is sometimes difficult to diagnose as it can often present as a rotator cuff syndrome. MRI can be useful for identifying soft tissue masses which may be impinging on the nerve, and EMG can be used to confirm diagnosis. Treatment includes the use of NSAIDs, rest, and rehabilitation specifically focusing on deltoid, rotator cuff, and periscapular stretching [25].

With most peripheral nerve injuries in wheelchair basketball players, therapy should be focused on teaching the athlete to use adequate range of motion and improve propulsion techniques. This should be done in an effort to decrease the push rates and forces involved in occurrences of neuropathies.

Spasticity

Spasticity is a potential problem in athletes who have suffered an injury to their central nervous system [26]. It is common to those who have a spinal cord injury, brain injury, cerebral palsy, or spina bifida. These disorders or injuries affect the upper motor neurons of the central nervous system. Spasticity is manifested by velocity-dependent increase in muscle tone, involuntary muscle contraction, and hyperreflexia [27]. Clinically, spasticity results from loss of inhibition of motor neurons, causing excessive muscle contraction leading to hyperreflexia [28].

When evaluating spasticity, it is important to keep in mind that some tone may provide assistance in activities. Spasticity can be helpful in posture, which is especially essential to performing in wheelchair basketball. However, when tone increases to the point where it begins to interfere with activity, intervention can be considered.

One of the most common methods of evaluation of spasticity is with the Modified Ashworth Scale. With the Modified Ashworth Scale, a joint is passively moved through its range of motion and a value is given to the amount of spasticity experienced during this movement [17] (see Table 12.3).

There are multiple methods and options for treatment of spasticity depending on the severity and regions of the body affected. Rehabilitation therapy including stretching and range of motion exercises are often used in addition to medical treatments. Oral medications can be considered for generalized spasticity; however, it is imperative to have a knowledge of substances which are banned by the World Anti-Doping Agency (WADA) for performance enhancement. The information for a specific medication and whether its usage is permitted or restricted can be accessed at www.globaldro.com. Oral medications which have been effective in reducing spasticity include baclofen, tizanidine, dantrolene, and gabapentin. When oral medication has failed, some patient may be appropriate for intrathecal baclofen. For areas where focal spasticity is noted, injections may be considered as a good option for treatment. Injections are typically performed with botulinum toxin or phenol [29].

Table 12.3 Modified Ashworth Scale [29]

0	No increase in muscle tone
1	Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion
1+	Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the range of motion
2	More marked increase in muscle tone through most of the range of motion, but the affected part is easily moved
3	Considerable increase in muscle tone, passive movement is difficult
4	Affected part is rigid

Endocrine

Osteoporosis is a reduction of bone mineral density which typically affects the geriatric population and women in particular. However, many disabled individuals are affected by osteoporosis long before they reach a geriatric age. Wheelchair users, and particularly spinal cord injuries, are susceptible to this disease due to the lack of activity and weight bearing on paralyzed extremities [18]. There is a significant loss of bone mass which occurs with immobilization. Wheelchair athletes with paralysis are vulnerable to fractures from osteoporosis. Fractures may be painless; therefore erythema, fever, or limb deformity should be noted during the physical evaluation [30].

Exercise and physical activity helps maintain this bone mass. Activities such as wheelchair basketball have been shown to improve bone density when compared to sedentary persons [18]. Osteoporosis prevention can also be aided through supplementation and encouraging weight-bearing exercises. The American Association of Clinical Endocrinologists

(AACE) recommends adequate calcium and vitamin D intake (via foods or supplements). The current recommended calcium intake is 1000 mg/day for men aged 50–70 and 1200 mg/day for both women over 50 and men over 70. NOF recommends vitamin D intake of 800–1000 IU/day, though other experts recommend up to 2000 IU/day. Additional AACE pharmacologic guidelines are as follows: First-line agents include alendronate, risedronate, zoledronic acid, and denosumab. Second-line agents include alendronate and raloxifene (though raloxifene is sometimes considered a third-line agent). The last-line agent is calcitonin. Treatment with teriparatide (an anabolic agent similar to PTH) may also be considered in patients with very high fracture risks or in those who have failed bisphosphonate therapy previously [31].

Heterotopic ossification (HO) occurs primarily in patients who suffered from neurologic disorders such as spinal cord injury and traumatic brain injury. Limb-deficient athletes secondary to amputation are also at risk if range of motion is limited [32]. The risk of heterotopic ossification is highest within the first 6 months after the neurologic injury. In athletes with neurologic injury, heterotopic ossification most often occurs at the hips, knees, shoulders, and elbows in this order [33]. Development of heterotopic ossification limits the function of the athlete, affecting the function and performance. Triple-phase bone scan is the current gold standard for diagnosis. It is specifically sensitive for early HO and may detect ectopic bone within 2–4 weeks during first and second flow phases. X-rays can detect HO within 3 weeks to 2 months of ectopic bone formation but can be more helpful to confirm maturity in HO. The appearance of mature HO on radiographs is often described as a “fluffy” or “popcorn-like” appearance of the bone. Ultrasound may have a role as a screening tool and may be obtained during DVT screening exam. Prevention includes aggressive range of motion. Treatment includes treating the underlying cause for spasticity and pain, NSAIDs, and bisphosphonates [34]. Surgery is recommended only after maturation of HO.

Cardiovascular

Autonomic dysreflexia is a dysfunction of the autonomic nervous system and should be of high concern for athletes with a spinal cord injury above the eighth thoracic level [35]. This may lead to significant and life-threatening complications involving the thermoregulation of the athlete’s internal body temperature. This may cause the body’s inability to cool itself through sweating or warm itself by vasodilatation mechanisms, both mediated by the autonomic nervous system. These athletes may not sweat effectively or have vasodilation below the level of their spinal cord injury leading to serious medical complications [36]. Medications are often used to treat autonomic dysreflexia, including anticholinergics, sympathomimetics, thyroid replacement therapies, but again there should be a review of restrictions of certain medications by WADA. The mainstay treatment is to evaluate and eliminate the noxious stimuli which may be causing autonomic dysreflexia [37] (see Fig. 12.6).

Wheelchair basketball players are also susceptible to episodes of low blood pressure, known as orthostatic hypotension. Players with spinal cord injury are particularly at risk for this condition due to pooling of blood in the abdominal viscera and lower extremities, combined with a decreased ability to have reflex vasoconstriction. Treatments of orthostatic hypotension can include non-pharmacological management with abdominal binders and elastic stockings as well as regulating water and salt intake [38]. Pharmacological interventions can also be considered with the use of midodrine, ephedrine, and fludrocortisone; however, these medications are banned for use in competition and would require an approval of a therapeutic use exemption (TUE) by the governing body [39] (see Fig. 12.7).

Fig. 12.6 Nationals

Fig. 12.7 Fayetteville

Conclusion

Wheelchair basketball has become and an increasingly popular sport within in the United States and internationally. Many players are those with spinal cord injuries, but amputees and those with a vast number of neurologic conditions are also participants. This population type combined with the rigor and athleticism required to continuously propel a wheelchair in a dynamic setting makes wheelchair basketball players susceptible to unique injuries. Furthermore there are inherent pathologies associated with spinal cord and other neurologic conditions which must also be considered in order to maximize a player's capacity. With the ever increasing popularity if this sport, it is important for medical practitioners to continue to identify and treat these conditions so as to allow for a player to reach his greatest function.

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13 Wheelchair Rugby

David M. Irwin, Monica K. Zillen
and Arthur Jason De Luigi

Introduction to the Sport

Wheelchair rugby is a co-ed, mixed team sporting activity for athletes with disabilities in all four limbs and most commonly due to a spinal cord injury resulting in tetraplegia. By definition, tetraplegia, also known as quadriplegia, is the paralysis of all four limbs. The motor and/or sensory function in the cervical spinal segments is impaired or lost due to damage to that part of the spinal cord. This injury results in impaired function to the upper limbs, lower limbs, trunk, and pelvic organs (Merriam-Webster Medical dictionary). These injuries most commonly occur between the cervical vertebral levels of C5–C7. The sport was created by disabled athletes who sustained a spinal cord injury. The founders combined elements of rugby, basketball, and handball, and it was known as “quad rugby” or “murderball” [1]. Initially the games were played using the athletes’ everyday wheelchair; however, the athletes sought out modifications to make sport-specific chairs that were more agile and to avoid damages to their everyday chairs. Manual wheelchairs are manufactured and modified specifically for the sport to help accommodate these athletes for competition [1]. The teams are composed of four players per side with the specific purpose of carrying the ball across the opposing team’s goal line. Wheelchair rugby is a contact sport between opposing teams’ players and wheelchairs. The contact is an integral part of the game and, like most contact sports, results in injuries. Wheelchair rugby classification rules require each athlete to meet a minimum disability criteria in order to be eligible to participate [1]. Wheelchair rugby is actively played in 26 countries and was introduced to the Paralympics in the summer of 1996 (Fig. 13.1) [1].

History

Originally called murderball, wheelchair rugby was invented in 1977 in Winnipeg, Canada. It was developed by Ben Harnish, a professor of architecture at Manitoba University, and two wheelchair athletes, Duncan Campbell and Gerry Terwin. Their goal was to create a sport based off of ice hockey and wheelchair basketball that allowed quadriplegic athletes, of varying disability, to participate equally in the game [1].

D.M. Irwin, DO
UPMC Hamot Medical Center, Erie, PA, USA

M.K. Zillen, DO (✉)
Lake Erie College of Osteopathic Medicine, Erie, PA, USA
e-mail: mzillen@gmail.com

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA
e-mail: ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_13

Fig. 13.1 Wheelchair Rugby Team. Photo Courtesy of Tiffanie Miner; Permission of use granted by Tiffanie Miner

The game was first demonstrated in 1979 at Southwest State University in Minnesota, USA. That same year, Canada held their first National Championship. The first US quad rugby team, North Dakota Wallbangers, was formed in 1981 by Brad Mikkelsen with the aid of the University of North Dakota's Disabled Student Services. The first US wheelchair rugby match was held in Marshall, ND, in 1982 between the North Dakota Wallbangers and the Minnesota Rolling Gophers. That same year, the University of North Dakota hosted the first International Quad Rugby Tournament [1].

The first US National Championship tournament was held in 1988 at the University on North Dakota. It was composed of six teams: Minnesota, Chicago, Detroit, Los Angeles, and North Dakota. During this tournament, the US Quad Rugby Association was formed to regulate and advertise the sport within the USA [1].

In 1993, the International Wheelchair Rugby Federation (IWRF) was formed during the World Wheelchair Games in England. The IWRF mission was (1) to create an international infrastructure for the sport, (2) to establish recognition from the International Paralympic Committee (IPC), and (3) to provide world-class competition [1].

After lengthy negotiations, wheelchair rugby was added as an exhibition sport in the 1996 Summer Paralympics. The USA won the gold medal, Canada won the silver medal, and New Zealand won the bronze medal [1].

During the summer of 2000, The Paralympic Games were held in Sydney, Australia. Wheelchair rugby was one of the most watched Paralympic events with over 10,000 viewers watching the championship game between the USA and Australia. The US team beat Australia by just one point making it one of the closest international finishes to date. New Zealand finished third and received the bronze medal over Canada [1].

In 2002, the world championship was held in Sweden. Canada beat the US team in the final game. In 2004, the Paralympics took place in Athens, Greece. New Zealand took the gold, Canada the silver, and the USA took the bronze [1].

The movie, *Murderball*, was released in 2004. This movie increased the sport's recognition and popularity. To this day, it has continued to assist in the recruitment of athletes to the sport [1].

The 2008 Paralympics were held in Beijing, China. The USA won the gold medal. Australia took the silver and Canada finished with the bronze medal.

The 2012 Paralympics were held in Great Britain. There was one event and eight teams competed. Although wheelchair rugby is considered a mix gender sport, the vast majority of competitors were male. Australia won the gold, Canada won the silver, and the USA took the bronze [1].

Year	Gold	Silver	Bronze
1996—Atlanta demonstration	United States (USA)	Canada (CAN)	New Zealand (NZL)
2000—Sydney	United States (USA)	Australia (AUS)	New Zealand (NZL)
2004—Athens	New Zealand (NZL)	Canada (CAN)	United States (USA)
2008—Beijing	United States (USA)	Australia (AUS)	Canada (CAN)
2012—London	Australia (AUS)	Canada (CAN)	United States (USA)

Adapted from the 2007 USQRA Coaches Manual, ©2004 by the US Disabled Athletes Fund, Inc.

The 2016 Summer Paralympics was held in Rio de Janeiro, Brazil, from September 7 to September 18.

Today, the International Wheelchair Rugby Federation boasts that wheelchair rugby is the only full-contact wheelchair sport in the world [1].

Who Plays It (Spinal Cord Injury)

Eligible participants who play wheelchair rugby must have a disability that affects both their arms and legs [1]. Many participants have spinal cord injuries, resulting in full or partial paralysis of their lower extremities and partial paralysis of their upper extremities. Despite the majority of players having spinal cord injuries, wheelchair rugby is also enjoyed by disabled persons with cerebral palsy, muscular dystrophy, amputees, polio, and other neurologic conditions that render them eligible to participate [1]. The majority of teams comprise both men and women. These co-ed's compete at the same level and in the same competitions. Each player is assessed by a medical professional, who is trained as a classifier, and given a classification based on their level of disability. Teams must comprise their four court players based on the classification given, to not equal a classification value greater than eight. Each team may exceed a classification value of 8 by 0.5 for every female on the court. This helps teams to field players with different functional abilities and level the playing field (Figs. 13.2 and 13.3) [1].

Fig. 13.2 Fallen Athlete. Photo Courtesy of Tiffanie Miner; Permission of use granted by Tiffanie Miner

Fig. 13.3 Match in Action. Photo Courtesy of Tiffanie Miner; Permission of use granted by Tiffanie Miner

A generalized classification table:

	Class 0.5
Typical role on court	Main role is as blocker, not a major ball handler
Chair skills/ function	• Due to extensive proximal shoulder weakness and lack of triceps function, forward head bob presents when pushing • Due to the lack of triceps, player pulls on the back part of the wheel for push stroke using the biceps by bending the elbows; elbows are also out to the side when pushing (aka "unopposed biceps push")
Ball skills/ function	• Due to proximal shoulder weakness and arm and wrist weakness, player traps direct passes on the lap or bats it in from a limited range

	Class 1.0
Typical role on court	Blocker, may handle in-bound ball, not a major ball handler
Chair skills/ function	• Due to proximal shoulder weakness and triceps weakness, player may have slight head bob when pushing but has a longer push on the wheel (combination of push and pull on the back of wheel) • Due to increased strength in upper chest and shoulders, multidirectional start, stop, and turn (can turn in all directions without stopping; easier and faster turning than 0.5 athlete; but because of triceps and wrist weakness, 1.0 athlete may still use forearm)
Ball skills/ function	• Forearm or wrist catch • Weak chest pass or forearm pass

	Class 1.5
Typical role on court	Excellent blocker and also may be occasional ball handler
Chair skills/function	• Increased shoulder strength and stability allows for more efficient pushing ball handling skills
Ball skills/function	• Increased shoulder strength and stability allows for some distance and consistency to chest pass • Typically has wrist imbalance that causes limited ball security when passing • May have asymmetry present in arms. If so, predominantly uses the stronger arm for chair and ball skills

	Class 2.0
Typical role on court	Increasing role on court as ball handler
Chair skills/function	• Typically has very strong and stable shoulders that allow for good pushing speed on court
Ball skills/function	• Effective chest pass with control over moderate distance • Due to lack of finger flexion, there is limited ball security against defense during passing • Can hold the ball with wrists firmly but does not have hand function

	Class 2.5
Typical role on court	Ball handler and fairly fast playmaker
Chair skills/ function	• Due to excellent shoulder strength and stability, player has good pushing speed • Functional grip is used to advantage on the push rim when challenged • May have some trunk control giving better stability
Ball skills/ function	• Reasonably balanced finger flexion and extension without true grasp and release • Dribbles the ball safely but supinates forearm to scoop the ball onto the lap • Due to finger flexion strength, player is capable of performing one-handed overhead pass, but with limited accuracy and distance because of imbalance in finger strength • Safe two-handed catching of passes, usually scooping ball to the lap. May catch passes single handed and scoop to the lap or chest • Improved ball security compared to 2.0 due to improved ability to isolate wrist/finger function • May have asymmetrical arm or hand function

	Class 3.0
Typical role on court	Very good ball handler and playmaker
Chair skills/ function	• Due to balanced finger function, athlete can grip wheelchair rim increasing wheelchair speed • May have some trunk control giving better stability
Ball skills/ function	• Due to function of fingers, can control the ball in varying planes of movement for passing, dribbling, catching, and protecting the ball • Can dribble and pass ball well with one hand • Multiple dribble one handed with control • Stabilizes with the opposite arm to allow greater reach

	Class 3
Typical role on court	Major ball handler and very fast playmaker. Often primary ball handler and playmaker on team
Chair skills/ function	• Has some trunk function, therefore very stable in wheelchair and able to use trunk for ball and chair skills
Ball skills/ function	• Due to a combination of hand and trunk function, usually has excellent ball control with controlled one-handed passing for distance and excellent ball security during passing and receiving • May have asymmetrical arm or hand function, noticeable with chair and ball handling skills

Rules of the Sport

1. *Equipment and field of play*
   Wheelchair rugby is played with a regulation volleyball. The use of manual wheelchairs is required for all athletes. These wheelchairs must meet specific guidelines set forth by the International Wheelchair Rugby Federation.
   The game is played on a hardwood basketball court measuring 28 m × 15 m, with marked boundary lines, a center line, a center circle, and two key areas. The two key areas, measuring 8 m wide and 1.75 m deep, are located on the two end lines and centered. The part of the end line that is in the key area is called the goal line. The ends of this line are marked with two cones (Fig. 13.4) [1].

2. *Players and officials*
   Each team may have up to 12 players and comprises both men and women. Each team can field four players at one time on the court. Each player is classified according to their functional disability with 0.5 being the lowest and 3.5 being the highest. 8.0 is the highest classification point value/team for all players on the court. A team is permitted an additional 0.5 points for each female player on the court. Each team designates one to two captains who are responsible for communicating with game officials. The game is supervised by two referees. The referees are assisted by four table

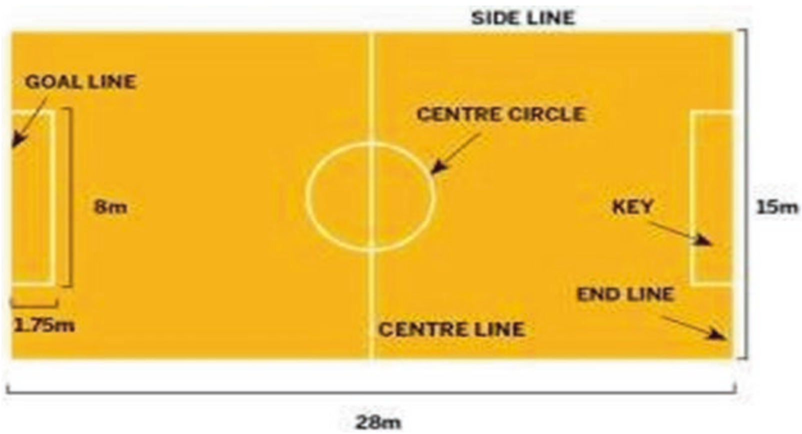

Fig. 13.4 Playing Field Configuration

officials: a scorekeeper, a timekeeper, a 40 s operator, and a penalty keeper. The technical commissioner supervises the work of the table officials and assists in deciding any protests brought forth by either team [1].

3. *Timing, scoring, starting, and stopping*
   Each game comprises 4 and 8 min quarters. There is a 2 min break between the first and second and third and fourth quarters.

   There is a 5 min break at halftime. The game is started with a tip-off. The game clock begins when the ball goes into play and is touched by a player. It stops with each break in play. The team in possession has 40 s to score a goal. Failure to score results in loss of possession. For the remaining quarters, an alternating process is used to determine possession. A goal is scored when a player carries the ball across the opposing team's goal line. The player must have complete ball control at all time and two wheels of their wheelchair must cross the goal line. After a goal or stoppage of the game, a "throw-in" is used to restart the play. Not more than 10 s can pass from the time the referee gives the inbounding player the ball until it has to be touched by another player on the court. Once touched by the player on the court, the ball becomes "live" again and the play and 40 s clocks start. The team with the highest number of points at the end of regulation is deemed the winner. If the score is tied, a 3 min overtime is played. If the score continues to be tied, subsequent 3 min periods are played until a winner is declared. Each team receives four player and two coach time-outs per game. Player time-outs are 30 s in length and coach time-outs are 1 min. A time-out can be called anytime the ball is "dead." Only the team in possession can call a time-out while the ball is in play. The referees can call a time-out at any time to respond to an injured/fallen player, damaged wheelchair, equipment failure/malfunction, or any other situation affecting the game or safety of the players. If a time-out is called due to equipment failure/malfunction, the affected team has 1 min to correct the problem or they must substitute with another player or use a time-out [1].
4. *Playing the ball*
   Players are allowed to play the ball with their arms or hands or carry it on their lap or chair. Three quarters of the ball must be showing if the ball is carried on a player's lap. A ball maybe passed by throwing it, rolling it, batting it, or bouncing it. Kicking the ball is prohibited. The location of the ball is determined by the location of the player. The location of the player is determined by the location of the four wheels of the wheelchair [1].
5. *Violations*
   Violations are committed by the team that has the ball in their possession. If a violation is committed, that team loses possession of the ball. Any player who has possession of the ball is prohibited from touching the floor with

any part of his body or wheelchair except for the wheelchair's four wheels and anti-tip device. The possessor of the ball must also dribble or pass the ball at least once every 10 s. The possessor of the ball is only allowed in the opposing team's key for a maximum of 10s. The team in possession has 12s to advance the ball to their front court and cannot return the ball to their back court once it has been advanced. The ball must remain in bounds at all times and the team in possession has a total of 40 s to score a goal. If any violations occur, loss of possession will occur [1].

6. *Fouls*

   Fouls can be committed by either team. There are four types of fouls: common fouls, technical fouls, flagrant fouls, and disqualifying fouls [1]. Common fouls occur when a player violates the rules during a genuine attempt to play the game. Technical fouls occur when a player or coach acts in a disrespectful or unsportsmanlike fashion, or violates the rules of the game. A flagrant foul occurs when a player commits a common foul with reckless disregard for safety. A disqualifying foul is any foul that is blatantly dangerous or unsportsmanlike. Each foul carries its own respective penalties [1].

Equipment (Modified Wheelchairs)

All wheelchair rugby athletes are required to compete in manual wheelchairs. These manual wheelchairs are manufactured and modified specifically for the sport and individual athlete. To begin, any manual sports wheelchair can be used. Many athletes start with a chair adapted for basketball although the game is much easier with a chair modified specifically for wheelchair rugby. The wheelchair is considered to be part of the player, and the correct setup is imperative for optimal function. Most wheelchair rugby participants use one of the two types of chairs: offensive or defensive. Offensive wheelchairs are set up for functionality. They have wings between the front bumper and rear wheels to prevent other wheelchairs from hooking it. They also have spoke guards flush with the push rim to prevent being picked or held by an opponent. They are generally faster, more mobile chairs. Defensive wheelchairs are set up for players with less function. They sit lower and have more camber (wheels set at an angle), and most of these chairs contain bumpers set up to hook and hold other wheelchairs. They typically have a long front end and an open space between the rear wheel and the front of the chair which maximizes the ability to hit and hold their opponent (hand book of SM, the paralympic athlete). They are usually slower and made to be more easily maneuvered for the player's specific impairment. The rules of the sport dictate detailed specifications including height, weight, length, wheel diameter, and cushion thickness that each wheelchair must meet to ensure safety and fairness. During international competition, each modified wheelchair must meet these specifications and pass inspection. Failure to meet these requirements will result in disqualification (Fig. 13.5) [1].

The official ball of wheelchair rugby is a regulation white volleyball. Although other balls can be used, for official play, a white regulation volleyball is required (Fig. 13.6) [1].

Fig. 13.5 Match in Action. Photo Courtesy of Tiffanie Miner; Permission of use granted by Tiffanie Miner

Fig. 13.6 Training Youth Participants. Photo Courtesy of Tiffanie Miner; Permission of use granted by Tiffanie Miner

Fig. 13.7 Wheelchair Rugby Team. Photo Courtesy of Tiffanie Miner; Permission of use granted by Tiffanie Miner

In addition to the wheelchairs and ball, four cones, pylons, or similar type of markers are required to mark the ends of the goal lines. These types of markers are preferably mobile to prevent player injury [1].

Two types of clocking devises are also used. There is a standard game clock and a 40-s score clock. Most of the time, any clock used for basketball, handball, or similar sport will suffice [1].

Common Injuries

As with any other contact sport, injuries are also common in wheelchair rugby (Fig. 13.7).

Musculoskeletal Injuries

Wheelchair athletes, like able-bodied athletes, are at increased risk for musculoskeletal injuries. Both athletes have comparable rates of injury; however, the ratio of these injuries differs quite significantly due to the predominant use of the upper extremities for wheelchair propulsion. Injuries to wheelchair athletes may affect their participation and performance to a higher degree than their able-bodied counterparts. Ferrara et al. noted that 32% of all injuries resulted in "time loss" of greater than 3 weeks [2].

Shoulder, elbow, wrist, and hand injuries are quite common. These injuries can present unilaterally or bilaterally. They occur equally frequent at each location and overuse is often the offending culprit [2]. Because of aggressive contact, wheelchair rugby athletes may have a higher ratio of traumatic injury compared with other wheel chair sports [3]. More than 90% of selected wheelchair athletes report a history of shoulder pain, with increasing prevalence to the amount of trunk and upper extremity disability [4–6]. Shoulder impingement syndrome is the most common injury associated with wheelchair athletes [7]. Rotator cuff and bicipital tendinopathies and tears are also common [7]. Wheelchair athletes often experience protracted scapular position with dynamic scapular dyskinesis, resulting in loss of subacromial space causing pain and dysfunction. Also, elevation of the humeral head results in relational muscle strength imbalance with a tendency to favor shoulder ABduction over ADDuction and rotation strength. Modifications such as trunk inclination, height of the backrest, and position of the wheelchair axle with relation to the shoulder can help reduce these risks. Physical therapy can help improve shoulder flexibility, correct scapular kinematics, and address shoulder muscle imbalances [7–9].

Lower extremity injuries are also common among wheelchair athletes but less common than able-bodied athletes [10, 11]. The nature of these injuries is usually acute and posttraumatic compared to the upper extremity injuries associated with overuse. The lower extremity injuries are often caused by direct contact with another wheelchair, object, or fall [2]. These incidents also increase the risk for head and neck trauma [2]. A higher rate of osteoporosis observed in this population can complicate these lower extremity injuries. Care providers must be diligent in their evaluations of even minor trauma because missed fractures could result in deformities and angulation after healing. The resulting consequences could alter functional status, increase the risk of pressure sores, and adversely affect available positions for seating.

Peripheral Nerve Entrapment

Wheelchair athletes often encounter peripheral nerve entrapments. Carpel tunnel syndrome has a prevalence in wheelchair athletes of approximately 50% [12]. Other associated entrapments include ulner neuropathies at the wrist and elbow, as well as radial neuropathies [12]. Suprascapular neuropathies can occur at both the suprascapular and spinoglenoid notches from shoulder muscle imbalance and scapular dyskinesis [13]. Protection with padded gloves and sleeves to the elbows and wrists, properly fitted equipment, proper technique, and adequate range of motion to decrease push rates and forces, in addition to standard techniques, are imperative for prevention and treatment [8, 14, 15].

Thermoregulation

Para- and quadriplegics have impaired thermoregulation. This impaired regulation is the result of altered sympathetic, vasomotor, and sudomotor responses [16, 17]. There are also decreased rates of venous return from the loss of muscle pumping action which results in a diminished ability to sense and respond to thermal imbalances [16, 17]. The loss of skeletal muscle and function, which leads to a reduced capacity for shivering, impairs the response to negative thermal imbalances [13]. The impairment of thermoregulation increases the risk of hypothermia and exertional heat illness, especially with spinal cord lesions at T6 and above [18].

Pressure Ulcers

Wheelchair athletes, especially those with a spinal cord injury, are at an increased risk to develop pressure ulcers. Pressure ulcers usually develop over bony prominent areas, most commonly the sacrum, coccyx, ischial tuberosities, and heels. Prolonged pressure combined with insensate skin that is moist from activity and increase compressive and shear forces cause local tissue ischemia and damage. Most wheelchair athletes maintain a flexed lower extremity posture at the knees and hips, secondary to altered trunk stability, which distributes the athlete's weight to "at-risk sites" [13]. Extremely vigilant care is vital for pressure ulcer prevention. The athlete must undergo frequent skin evaluations and weight shifting every 15–20 min to relieve pressure and compressive forces, with properly fitted equipment, and maintain a dry environment [24].

Spasticity

Spasticity is common in wheelchair athletes, especially those with spinal cord injuries. The injuries are manifested by involuntary muscle contractions, hyperreflexia, and velocity-dependent increases in tone [24]. Synergistic muscle activation patterning may inhibit performance by altering positioning within the wheelchair, item control/accuracy, and propulsion [24]. Important to note, spasticity may be beneficial to function when voluntary muscle action is insufficient. It is important for the sports physician to remember that spasticity is primarily a velocity-dependent increase in tone and thus routine bedside examination may not be conductive to a thorough appreciation of the detrimental effects of spasticity unless sports activities are entirely replicated [24].

Treatments for most spasticity include oral medications, intrathecal medications, and physical therapy. Physical therapy should concentrate on a range of motion and tone-reducing orthoses. In more advanced cases or in cases where the athlete cannot tolerate the sedative effects of antispasticity medications, botulinum toxin injections can focally reduce high levels of spasticity in dose-dependent fashion [24]. In extreme cases, surgical interventions such as muscle/tendon lengthening, tendon transfers, and selective dorsal rhizotomies may provide necessary function and relief of pain.

Neurogenic Bowel and Bladder

Bladder dysfunction is common in wheelchair athletes with spinal cord injuries and spina bifida [24]. The nature of this dysfunction leads to urinary retention resulting in indwelling, suprapubic, or intermittent catheterization. These treatments can lead to increased urinary tract infections, stone formation, and trauma from the catheters. Clinical presentations include fever, fatigue, malaise, autonomic dysreflexia, incontinence, and an increased level of muscle spasticity [24].

Bowel dysfunction is also common in athletes with spinal cord injuries and spina bifida. Injuries to the spinal cord above the S2 level can result in a reflexic neurogenic bowel; injuries distal to this level, involving destruction of the anterior horn cells, can result in an areflexic bowel [24]. Patients are counseled to initiate a regular bowel regimen at the same time of the day to condition the bowel to achieve effective defecation and avoid incontinence [24].

Due to an overfocus on training, wheelchair athletes may not adhere to a properly regimented bowel and bladder routine. This inadherence can lead to increased infections, incontinence, dehydration, and hospitalization. Practitioners should counsel these athletes on the importance of a vigilant bowel and bladder regime and implement these to best accommodate their competition schedules.

Heterotropic Ossification

Heterotropic ossification (HO) may occur in up to 36% of patients with spinal cord injuries, and amputees competing in the wheelchair class may also be at risk [19]. The highest risk for the development of HO is approximately 4 months after spinal cord injury. HO most commonly occurs around the hips but may also affect the knees, shoulders, and elbows [19]. Patients generally experience limited range of motion and function inhibiting their ability for propulsion and other tasks. HO can also increase the risk for pressure sores and nerve entrapments.

Autonomic Dysreflexia

Autonomic dysreflexia is a potentially life-threatening medical emergency and occurs in patients with spinal cord injuries at or above the T6 level. Noxious stimulation below the level of injury causes reflexive sympathetic activity that cannot be modulated by supraspinal centers of control, resulting in high levels of sympathetic activity below the lesion and incomplete parasympathetic compensation above the lesion [19]. Patients in crisis often experience critically high blood pressure, often with systolic pressures greater than 200 mmHg, severe headaches, blurred vision, profuse diaphoresis, bradycardia, facial erythema, cutisanserina, acute rhinitis, and a "feeling of doom" and/or apprehension. Complications include seizures, pulmonary edema, myocardial infarction, or cerebral hemorrhage. Treatment should start with properly diagnosing the condition as autonomic dysreflexia and removing the noxious stimuli, administration of antihypertensives, removing restrictive clothing, sitting the patient up to further reduce blood pressure, straight catheterization of the bladder, and manual evacuation of the stool vault.

An unsettling trend among wheelchair athletes is the intentional use of autonomic dysreflexia to improve performance during competition, a phenomenon known as "boosting" [24]. Athletes create a self-induced noxious stimulus in order to induce the dysreflexia. This strategy can lead to increased peak heart rate, oxygen consumption, and blood pressure. It has also been shown to enhance "race time" by 10% [20–22]. For obvious health and safety reasons and to promote fairness during competition, the International Paralympic Committee has banned the use of induced autonomic dysreflexia from the competition [23].

In conclusion, wheelchair rugby was founded by combining multiple sports for the love of competition by quadriplegic athletes. The comradery and team effort draw quadriplegic athletes to the sport. The aggressive nature of the sport reminds these athletes that they are more than their injuries and can bring a tremendous amount of joy and accomplishment. As with any sport, injuries are common and treatable. It is important for the athletes with special needs to be aware of their enhanced risk of injury and illness as well as the plethora of health benefits provided by daily physical activity. Clinicians must be ever vigilant in their care of these athletes, familiarize themselves with the sport, and perform thorough physical examinations. Through the due diligence of the federation, athletes, and physicians, quadriplegic athletes are able to enjoy healthy, safe, and fair competition at an optimal level (Fig. 13.8).

Fig. 13.8 Match in Action. Photo Courtesy of Tiffanie Miner; Permission of use granted by Tiffanie Miner

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Power (Wheelchair) Soccer

14

Alexander M. Senk

Abbreviations

AE	Athletic-event exposures
cm	Centimeter(s)
FIFA	Fédération Internationale de Football Association
FIPFA	Federation Internationale de Powerchair Football Association
g	Grams
HR_{max}	Maximal heart rate
IPC	International Paralympic Committee
IPFA	International Powerchair Football Association
kg	Kilogram(s)
m	Meter(s)
m/s	Meters per second
USA	United States of America
USPSA	United States Power Soccer Association

Introduction [1]

In 1978, a version of European football with the use of power wheelchairs began in France. Shortly later in 1979, a different form called "power soccer" was independently developed in Canada. Over the next quarter century, a number of other countries including the United States began playing variations of the sport. It was not until October 2005 that representatives from Belgium, Canada, Denmark, England, France, Japan, Portugal, and the United States convened in Paris, France, to collaborate on elevating the game to an international sport [2]. This required review of the various rules and styles of play to develop one cohesive set of rules and regulations for international play. Thus, the International Powerchair Football Association (IPFA) was created.

The momentum behind this movement continued leading to the formation of the Federation Internationale de Powerchair Football Association (FIPFA) by July 2006 and the first World Cup being held in October 2007 in Tokyo, Japan (Table 14.1). By 2009, FIPFA gained the status recognition of "Federation" by the International Paralympic Committee (IPC). This was major step as it is a requirement for consideration to become part of the Paralympic Games.

After an unsuccessful bid for the 2016 Paralympics in Rio de Janeiro, Brazil, powerchair football was submitted for consideration to

A.M. Senk, MD, FAAPMR, CAQSM
PM&R Sports Medicine, Minneapolis Veterans Affairs Medical Center, 1 Veterans Drive, Minneapolis, MN 55417, USA

Mountain Area Health Education Center—Mission Sports Medicine, 123 Hendersonville Road, Asheville, NC 28803, USA
e-mail: alexander.senk.md@gmail.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_14

be part of the 2020 Paralympics in Tokyo, Japan [3]. Unfortunately, it failed to make the final cut of the 22 approved sports [4]. If it had been accepted, it would have become the first power wheelchair-based sport in the Paralympic Games.

Major competitions for this sport include the Americas Cup (the United States vs. Canada), Power Champions League in Europe, European Nations Cup, and Copa Powerchair Liberators (Latin-American countries). In 2014, FIPFA held the first international tournament for athletes under 18 years of age.

Table 14.1 Power soccer around the world in 2016

Argentina○	Germany	Singapore
Australia○	Hong Kong	South Korea*
Austria○	India	Spain○
Belgium*♦	Ireland○	Switzerland○
Brazil○	Italy	Turkey
Canada*○	Japan*○	United States of America*○
Denmark*○	New Zealand	Uruguay○
England*○	Poland	Wales
Finland○	Portugal*○	
France*○	Scotland	

The table identifies the 28 countries where power soccer was practiced in 2016. It also denotes the 8 founding countries (*) of FIPFA as well as its 16 current (○) and past members (♦)
Table created by Alexander Senk, MD

Basics of Competition [5, 6]

Field of Play (Fig. 14.1)

Dimensions

Power soccer is typically played indoors on a standard size basketball court (28 m × 15 m). The court must be at least 25 m × 14 m and can be as large as 30 m × 18 m. The goals are demarcated by two moveable, upright posts spaced 6 m apart (Fig. 14.2).

Surface

To facilitate safe maneuverability of the power wheelchairs, the field of play requires a hard, level, and smooth surface. Use of wood and artificial materials is recommended, while use of concrete and blacktop is discouraged. This may promote the longevity of the wheels of the powerchairs while reducing the risk of tipping and decrease the severity of abrasions if tipping were to occur.

Equipment

Besides needing the appropriate venue, there are two major requirements to play: a power soccer ball and adapted power wheelchairs. Additional equipment required for formal competition includes color-coordinated team jerseys for the

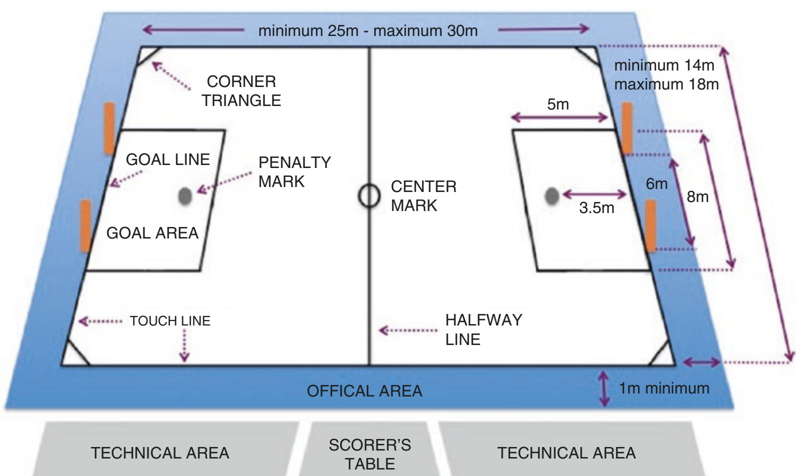

Fig. 14.1 Diagram of power soccer field. The diagram details the dimensions of a standard power soccer field and identifies additional required areas that are outside of the field of play. Figure credit Alexander Senk, MD

Fig. 14.2 Power soccer goal. The photograph depicts a typical power soccer goal with goalposts from an anterior perspective. Photo credit Brionn Tonkin, MD. Courtesy of Courage Kenny Rehabilitation Institute

Fig. 14.3 Power soccer ball size comparison. The image reveals a standard-sized power soccer ball with its dimensions next to a common folding chair for a size reference. Photo credit Brionn Tonkin, MD. Edited by Alexander Senk, MD. Courtesy of Courage Kenny Rehabilitation Institute

upper and lower body with clearly visible numbers. Goalkeepers should wear distinguishing apparel. All players are advised to not use equipment that may cause harm to oneself or others. This includes medical equipment that is nonessential during play.

Ball

The ball used to play power soccer closely resembles that of traditional soccer ball or European football (Fig. 14.3). It is an inflatable, spherical ball with a low-friction outer covering such as leather or vinyl. It measures 33 cm in diameter and weighs approximately 1 kg. The ball is inflated to a level that minimizes bouncing while preventing enough compressibility to be run over.

In comparison, a traditional soccer ball used in Fédération Internationale de Football Association (FIFA) matches has a 22 cm diameter and weighs 410–450 g [7]. Thus, a power soccer ball carries approximately twice the amount of force for any given acceleration.

Adapted Power Wheelchair

To be used in play, a power wheelchair must have at least four wheels. The front of the powerchair is equipped with a foot guard or shroud whose purpose is threefold (Fig. 14.4). While protecting the competitor's lower extremities, it enables striking and passing & prevents trapping of the ball. If desired, a rear guard may also be attached. It is subject to the same specifications as the foot guard.

Custom designs for foot guards and rear guards are allowed, but they must be fabricated from an unbreakable material. The use of plastic and steel are common. In addition, the guards must be flat to convex with smooth edges and no protrusions. Angling of the guards is not permitted during construction or fastening to the powerchair as it may promote elevation of the ball posing a risk of harm to competitors. Designs with a concavity are also not permitted as they would enable a cradling effect. Frontguards must extend at least the width of the front casters but no further than the widest part of the individual power wheelchair. Collectively, these measures should prevent any holding, trapping, or rolling-over the ball.

Lap seat belts are mandatory. Additional safety features such as restraints (i.e., chest strap, leg straps) and headrests may be implemented according to the tailored needs and preferences of each player (Fig. 14.5). Only essential medical equipment, such as tube feeding, oxygen, or ventilators, should be attached to power wheelchairs during play.

Regardless of the number of wheels, scooters are not permitted in sanctioned events.

Adaptive athletes can operate powerchairs by any system tailored to meet their functional needs. For instance, some individuals utilize a joystick

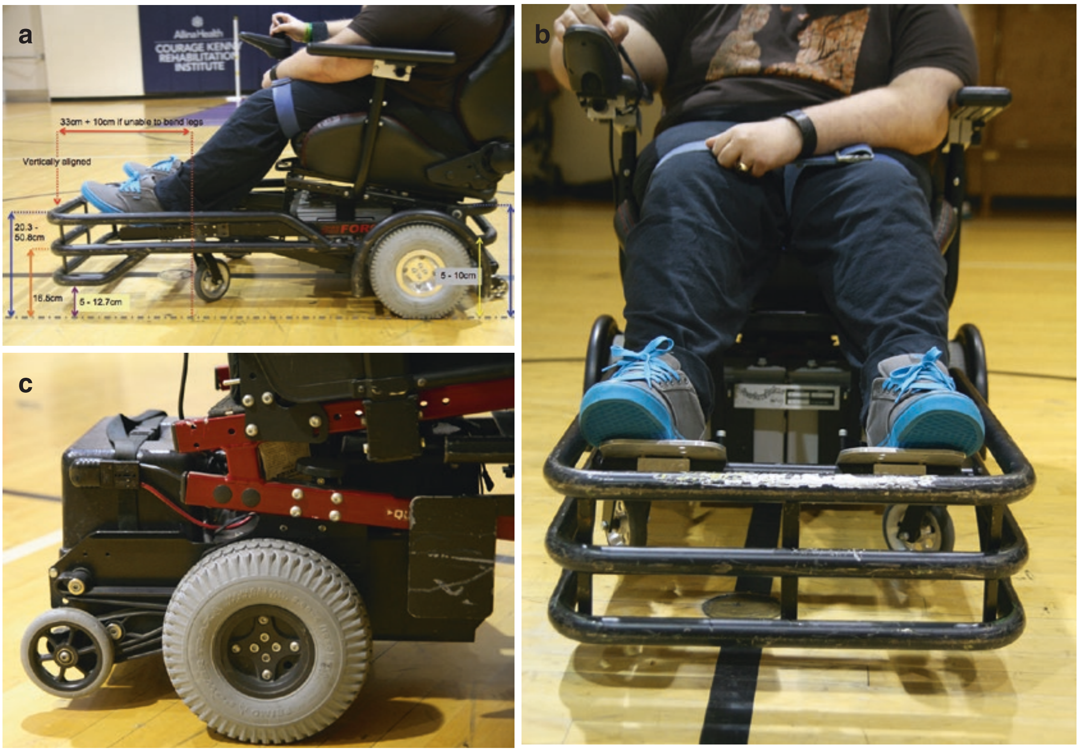

Fig. 14.4 Foot guard and rear guard specifications. The following images capture three different viewing angles (lateral, anterior, posterior) of a power wheelchair adapted for power soccer play. Images **a** and **b** show an example of a foot guard with specifications from a lateral and anterior point of view, respectively. Image **c** is taken from a posterior perspective to demonstrate a powerchair without a rear guard. (**a**) Lateral view: Photo credit Brionn Tonkin, MD. Edited by Alexander Senk, MD. Courtesy of Courage Kenny Rehabilitation Institute. (**b**) Anterior view: Photo credit Brionn Tonkin, MD. Courtesy of Courage Kenny Rehabilitation Institute. (**c**) Powerchair without a rear guard: Photo credit Brionn Tonkin, MD. Courtesy of Courage Kenny Rehabilitation Institute

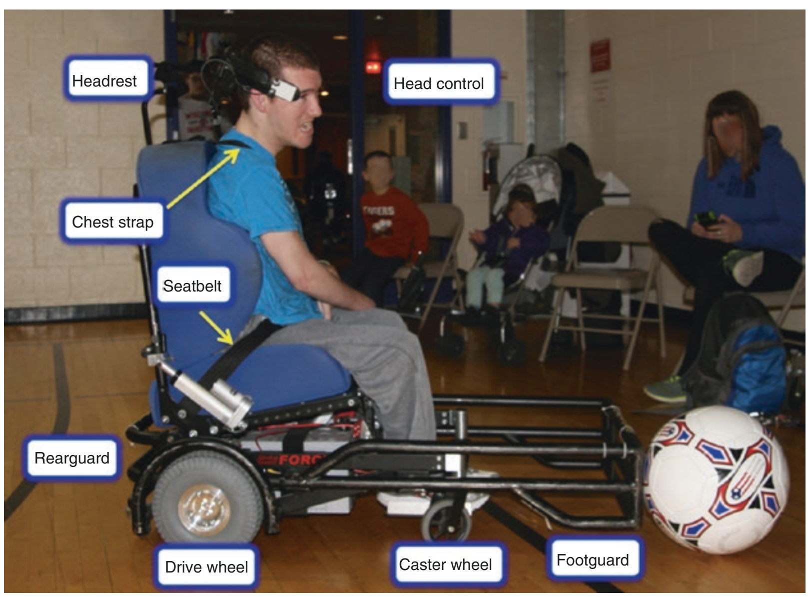

Fig. 14.5 Power wheelchair features. The image identifies common features of powerchairs adapted for power soccer. Photo credit Brionn Tonkin, MD. Edited by Alexander Senk, MD. Courtesy of Courage Kenny Rehabilitation Institute

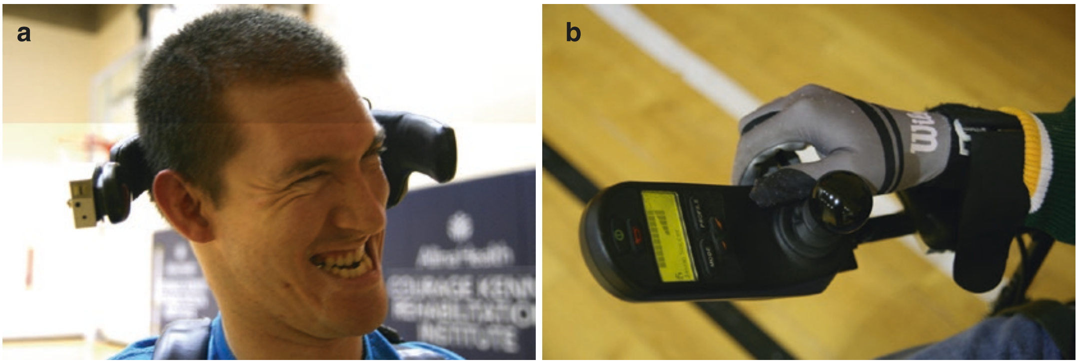

Fig. 14.6 Power wheelchair controls. Powerchairs are operated by a variety of control systems. Images **a** and **b** are two examples used by participants to play power soccer. (**a**) Head control: Photo credit Brionn Tonkin, MD. Courtesy of Courage Kenny Rehabilitation Institute. (**b**) Joystick control: Photo credit Brionn Tonkin, MD. Courtesy of Courage Kenny Rehabilitation Institute

control system while others who lack sufficient strength or dexterity in their upper extremities may utilize a head control system (Fig. 14.6).

Power Wheelchair Biomechanics

During matches, the maximum speed allowed for powerchairs is 2.7 m/s or 10 km/h (6.2 mph), which coincides with most electric-powered wheelchair capabilities [3, 4, 8]. This speed restriction is for all directions including reverse. Rear wheel drive powerchairs have gained popularity due to their speed and ability to quickly turn which elevates some players' performance [9].

Participants tend to vary their speed according to match play. This positively correlates with a study by Kumar et al. based on the 28th and 29th National Veterans Wheelchair Games. They found that power soccer players averaged a speed of 0.8 ± 0.2 m/s with approximately 31% of game time spent at speeds exceeding 1 m/s, 16% between 0.5–1 m/s, and 21% below 0.5 m/s [10]. The average distance traveled by each contestant during the games was about 900 m [8].

In comparison, power wheelchairs being used as functional mobility aids in a community setting typically operate at speeds around 0.4 m/s [6].

Match

There are two 20-minute periods in each match with up to a 10-minute halftime. Before play starts, the duration of the periods and intermission can be changed if mutually agreed upon among the referees and two teams. The addition of stoppage time, such as time lost during injury evaluations or mechanical malfunctions, is at the discretion of the referee. Both teams have two 2-minute time outs per half.

Each team may consist of a total of eight players with up to four players in the game and four substitutes. One of the athletes in play must always be a goalkeeper. The minimum permissible number of players allowed for a team to begin a competition is two, and the maximum number of PF2 status players on a team engaged in a FIPFA-regulated competition is two. (See Sect. "Classifications" for further information.) Substitutions are permitted during stoppage of play during the match. To play, one must be at least 5 years old and be able to properly control his or her power wheelchair. This may be performed by any variety of control systems (Fig. 14.7).

Game Play

Scoring

In order to score a goal, the entire ball must cross the goal line without any infractions of the rulebook during play. If a goalpost is missing or becomes strewn during the action, a goal is awarded if majority of the ball crosses inside of the respective marker and completely passes the goal line (Fig. 14.8).

The victor is the team with the most goals at the end of regulation. If the score is even, the

Fig. 14.7 Power soccer game action. The photograph captures live game play. Photo credit Brionn Tonkin, MD. Courtesy of Courage Kenny Rehabilitation Institute

Fig. 14.8 Power soccer goaltending. The image illustrates real-time goaltending. Photo credit Brionn Tonkin, MD. Courtesy of Courage Kenny Rehabilitation Institute

match is drawn. It may be further decided by playing in overtime or a shootout.

Officiating: Referee ± Assistants [11]

The United States Power Soccer Association (USPSA) has established specific criteria for credentialing of referees to ensure consistent and appropriate officiating. There are four levels of USPSA referee accreditation referred to as grades: grade 4, assistant referee; grade 3, referee; grade 2, regional referee; and grade 1, national referee. The grades are differentiated by minimum age (13, 17, 19, and 21 years old respectively), nomination, experience, time spent in current grade, completion of USPSA courses, performance on a standardized written examination, and field assessment. These are all taken into account when determining if an individual is suitable for a promotion or demotion. FIPFA utilizes a similar criterion for international referees.

Most games are officiated by a three-person crew consisting of one referee and two assistant referees. In certain circumstances, a fourth official may be appointed. It is their responsibility to enforce the Laws of the Game as dictated by the governing body of the sponsoring entity (i.e., FIPFA for international play, USPSA for local, regional, or national play within the United States).

As its name might suggest, power soccer is regulated by rules that mirror its FIFA predecessor. However, there are at least two distinct differences: kick-ins have replaced throw-ins to return the ball to play and offsides was eliminated. Instead of offsides, there is a field position rule which promotes a more free flowing game.

Table 14.2 Power soccer penalties [3, 4, 12]

Minor fouls		Major fouls
10 foot violation	Goal zone violation	Ramming
Backing up	Hand ball	Unsportsmanlike conduct
Charging	Holding	
Clipping	Loss of control	
Delay of game	Redirection of chair	
Goal tending		

Power soccer has two categories of fouls: minor and major. The table provides examples of each type of infraction
Table created by Alexander Senk, MD

Fouls

Penalties have been categorized as minor and major fouls (Table 14.2). A player is ejected from a game after accruing three major fouls. Each major foul awards the opposing team a penalty kick. Yellow and red cards may be given to players as in FIFA style of soccer.

Classifications [3]

Prior to competition in a FIPFA-sanctioned event, every player must be allocated into a sports class. This process ensures that each participant meets eligibility requirements, which consists of being diagnosed with a severe physical impairment that results in a verifiable, permanent activity limitation and dependency on powered mobility to engage in athletics. It also is implemented to promote fair and equal competition by minimizing the effect of a team's overall functional impairment on the outcome of a game.

There are two sports classes in powerchair football: PF1 and PF2. PF1 athletes have high levels of physical limitations affecting their performance. PF2 individuals have mild to moderate physical difficulty but remain complaint with the minimal eligibility criteria.

Of note, age, cognition, gender, fitness level, and skill are not considerations when classifying participants.

Injury Epidemiology

Power soccer is considered a contact sport. As such, there is an inherent risk of injury facing all participants. To date, there are no prospective studies stratifying the most common injuries affecting powerchair footballers. This paucity of information is consistent with adaptive sports at large. However, advances in the data acquisition on injury profiles and detailing of its analysis in peer-reviewed journals are improving.

Prospective studies have found an injury rate ranging from 2.0 to 9.3/1000 athletic-event exposures (AE) in adaptive sports across all disability levels [13, 14]. In comparison, American college football had an injury rate of 10.1–15.0/1000 AE, soccer 9.8/1000 AE, and men's basketball 7.0/1000 AE [11]. Of the injuries sustained by athletes with functional impairments, 52–70% were considered minor [11]. These correlated with the participants' disability status and respective sport. For instance, upper extremity injuries tend to occur in individuals with spinal cord injuries while lower extremities ailments are more common in those who ambulate [11].

Injury Prevention

When participating in power soccer, using proper equipment is key to reducing the incidence of injuries. This is vital as injuries may not only affect players' performance or ability to play, but it may also compromise their overall functional independence. Hence, there is an emphasis on primary prevention of sports-related injuries. These strategies are often based on conjecture extrapolated from studies on able-bodied athletes and experience of medical providers and adaptive athletes [15]. Nonetheless, there are efforts to validate current recommendations and to bring to light novel approaches to optimize player safety.

The use of scooters should be avoided as they have a twofold increased risk of injury [16]. Scooters have a tendency to tip over sideways while power wheelchairs are more likely to tip forwards [14]. Tipping occurs more commonly from engineering errors and environmental factors. However, improper placement of foot guards and playing with an underinflated ball may pose a hazardous risk. The use of foot guards and rear guards meeting FIPFA and USPSA specifications may reduce this danger.

Lap seatbelt use reduces the risk of participants falling and being ejected from a power wheelchair during play [17]. The risk of being ejected during a fall is more common when using rear-wheel drive powerchairs. This occurs for the same reasons that attract competitors to use them: faster speeds and quicker turns.

Standard precautions should be made to address common medical issues affecting individuals with physical limitations from neurologic disorders. These precautions include special attention to environmental factors as they may have impaired ability to adapt to warmer and cooler conditions secondary to underlying autonomic dysfunction. For those who are insensate or have impaired sensation in their lower extremities, a formal seating evaluation may help reduce the risk of pressure ulcers by evenly distributing their body weight. While engrossed in competition, power footballers may benefit from reminders to perform routine pressure relief techniques. Teammates, coaches, and medical staff should also be familiar with potential life-threatening conditions such as autonomic dysreflexia. Boosting or the intentional induction of autonomic dysreflexia for an advantage is prohibited by the IPC and should be discouraged due to adverse health effects related to the unregulated hypertension [18].

Majority of safety guidelines, Laws of the Game, and other precautionary strategies are focused on primary prevention. One area that could benefit from future bolstering is secondary prevention. Snodgrass et al. found that only 30% of athletes injured during wheelchair sports competition were evaluated at the time of injury by a medical provider of any background or training level [19]. By expanding medical coverage of such events, we may find an overall reduction in injury complication rates, which is yet to be defined, and return-to-play times due to proper early medical management. To achieve this goal, further education of medical providers on the array of diseases and disorders affecting the adaptive athlete may prove fruitful to improving comfort level with identifying and treating medical issues unique to this population. This in turn may help available community medical coverage and resources grow.

Benefits of Participation

In general, maintaining an active lifestyle with regular exercise has been shown to be beneficial in able-bodied and disabled individuals. Perceived benefits of exercise by powerchair footballers include improved quality of life via enjoyment of the activity but most notably the social engagement, which can help foster comradeship locally to internationally [20, 21]. A study by Evans et al. found that power wheelchair football was the most common social use of electric-powered indoor-outdoor wheelchairs in adolescents ranging from 10 to 18 years of age in the United Kingdom [22].

It also aids in risk reduction of secondary medical comorbidities including anxiety, depression, obesity, and pain [10, 18, 23]. This is important, as obesity is more prevalent in people with disabilities than those without, 41.6%–29.2%, respectively [22]. In addition, obese individuals with disabilities are at a comparatively higher risk of developing diabetes mellitus, hypercholesterolemia, hypertension, and elevated C-reactive protein levels than obese people without disabilities [24].

The positive effect of participating in an organized sport such as power soccer should not be understated. A study by Sporner et al. on the psychosocial impact of veterans participating in the National Veterans Wheelchair Games and Winter Sports Clinic found that it helped 84% of the subjects have improved acceptance of their disability [25]. Another consistent theme identified is enhanced confidence and self-esteem and re-identification of self as an athlete [17, 19].

Barriers to Participation

In 2011, the World Health Organization estimated that 15.6% of the world population has a form of disability, including 70 million children worldwide aged between 15 and 18 years old [26]. In the United States alone, there are over 5 million children with disabilities participating in special education programs. Amendments made to the Individuals with Disabilities Education Act in 2004 as well as state-specific special education plans made provisionary mandates for transition services. These may include utilization of adapted physical education specialists to facilitate the development of individual education plans that incorporates physical education and other extracurricular activities [27].

Impaired functional mobility is a barrier for participation in exercise and organized athletics for those with neuromuscular dysfunction. Use of wheelchairs can circumnavigate this barrier and enable such populations to engage in meaningful exercise [18]. However, it can be a challenge for wheelchairs to utilize public transportation services and to access playgrounds. This is a likely contributing factor to one of the more common complaints of there being a lack of places for people with disabilities to exercise [18]. While required to pay the same amount for a fitness center membership as an able-bodied person, it is not uncommon that people with functional impairments find there to be insufficient amounts of adaptive equipment and inadequate wheelchair accessibility to other exercise gear [28].

Emotional and psychological barriers can affect the utilization of accessible resources. A focus group analysis by Rimmer et al. found that the atmosphere of a gym and its construction could deter people. For instance, the lack of front desks of a suitable height for wheelchair users to comfortably and effectively communicate has been reported to immediately put some at unease [26].

Other factors that may negatively influence participation in exercise are the preconceived notions held by some with disabilities. Barfield and Malone found that some people with muscular dystrophy are deterred from engaging in exercise as they feel it is not as important for them while majority of those with disabilities avoid it due to its difficulty and associated fatigue [18]. Hence, power soccer may provide a valuable alternative to traditional wheelchair-based exercise as it has been found to elevate the resting heart rate in disabled athletes. In fact, 71% of subjects with cerebral palsy and muscular dystrophy exceeded 55% of their estimated maximal heart rate (HR_{max}) for at least 30 min during power soccer competition [29]. This finding is significant as individuals with lower cardiorespiratory reserve may improve their fitness levels through aerobic exercise that achieves ≥55% HR_{max} [30].

Special Considerations [31]

Often in sports, an athlete or a team can catch the eye of the public and become an inspirational figure. An exploratory qualitative study by Cottingham et al. examined power footballers' response to such recognition and associated accolades. They found that some of the adaptive athletes had reservations regarding such sentiments while other felt they were degrading and belittled their accomplishments.

Summary

Power soccer affords adaptive athletes and individuals with significant physical limitations the opportunity to engage in recreational to competitive level sports. Like any collision sport, there is an inherent risk of injury associated with it; however, the exact risk and injury epidemiology for powerchair football have yet to be determined. However, there are studies that have elucidated the health benefits ranging from cardiovascular to psychological effects. As power soccer continues to grow within the international adaptive sports community, accessibility to the appropriate equipment and sports arenas will hopefully continue to improve to make it more universally available for all.

Acknowledgments I would like to thank Brionn Tonkin, MD, for his mentorship and photographic prowess; Taavasa "Junior" Mamea and Courage Kenny Rehabilitation Institute for their support to this endeavor and to adaptive athletes; Aaron Vaughan, MD, for his insightful review; Sue Stigleman and the Mountain Area Health Education Center Library staff for their assistance in the research and article procurement; and Hervé Delattre and Barb Peacock, president and general secretary of the Federation Internationale de Powerchair Football Association, for their historical references. Lastly, I would like to thank my wife, Cat, for enabling me to chase dreams.

Photographs are courtesy of Brionn Tonkin, MD, and the Courage Kenny Rehabilitation Institute in Golden Valley, MN.

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Wheelchair Softball

15

Daniel H. Blatz and Craig Ziegler

Classification Process for Wheelchair Softball Athletes

Wheelchair softball allows participation of athletes with impairment from multiple disability groups. However, the obvious requirement is the need for a wheelchair (see Picture 15.1). These disabilities include spinal cord injury, congenital malformations effecting the lower extremities, amputations, and injuries/illnesses effecting lower extremity strength and mobility. In order to allow fair competition between these athletes with varying disabilities, a classification system has been developed.

To ensure balanced and fair teams, players and teams are assessed via a point system as specified by the National Wheelchair Softball Association (NWSA) delineated below [1, 2]. The classification process assigns a certain number of points based on the level of injury, impairment, and/or function. A quadriparetic athlete is assigned one point, a Class I athlete is assigned one point, a Class II athlete is assigned two points, and a Class III athlete is assigned three points.

D.H. Blatz, MD (✉)
Shirley Ryan AbilityLab (formerly Rehabilitation Institute of Chicago), Chicago, IL, USA
e-mail: dblatz@sralab.org

C. Ziegler, MD
Department of Orthopedic Surgery, Washington University, St. Louis, MO, USA

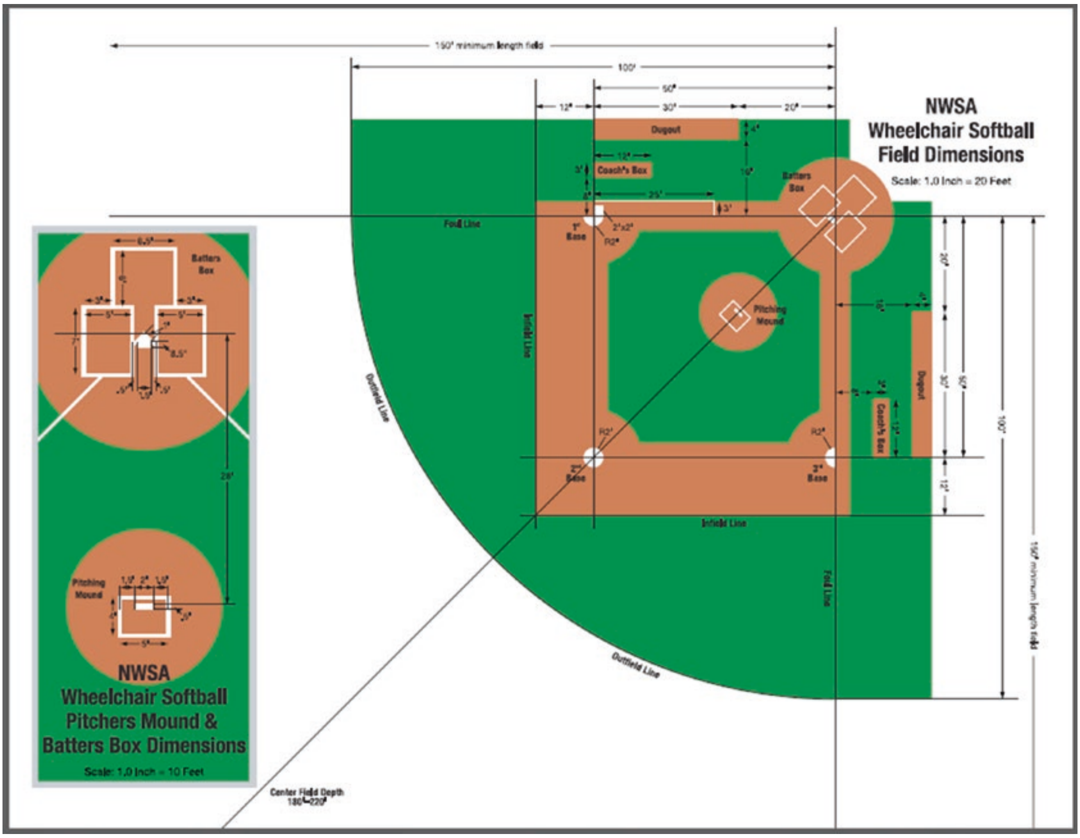
A Class I athlete is one that has complete motor loss at T7 or above or a comparable disability where there is total loss of muscle function originating at or above T7. Class I athletes should not have functional use of abdominal musculature, their trunk control and sitting balance should be poor to absent, and they should have a weak cough. A quadriparetic athlete is one that has motor impairments affecting all four extremities.

A Class II athlete is one with complete motor loss originating at T8 and descending through and including L2 where motor power of the hips and thighs may be present. Class II athletes should have no practical motor strength below L2, only grade 2 quadriceps strength, grade 3 hip abductors, and grade 4 hip flexors (see Appendix for muscle strength grades). This class also includes amputees with bilateral hip disarticulation.

A Class III athlete is one with any other physical disabilities leading to lower extremity paralysis or paresis at or below L3. Class III athletes should have motor paralysis or paresis originating at or below L3, good trunk control, good pelvic control, and good sitting balance. This class also includes all lower extremity amputees except ones with bilateral hip disarticulations.

Each team fields a maximum of ten players at a time. At any one time a team's participating players can have a total value of no more than 22 points based on the above classification system.

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_15



Picture 15.1 The 2015 Chicago RIC Cubs wheelchair softball team

Rules and Regulations of the Game

Wheelchair softball follows the same basic rules and guidelines as those that were established by the American Softball Association (ASA) for 16 inch softball [1]. Due to the adaptive nature of the sport, there are a number of additions and modifications which we present below.

Field Setup

One of the most important aspects of wheelchair softball is the field setup. The details regarding basic wheelchair softball field setup is listed below [1].

- Level, smooth playing surface of blacktop or similar materials.
- Dimensions of 150 ft. on foul lines and 180–220 ft. to straight center.
- 50 ft. between all bases and 70 ft. 8.5 in. from home to second base.
- Pitching stripe located 28 ft. from home plate and extending one foot on either side of diagonal from home to second base.
- Four foot diameter circle at second base. At first and third base, a four foot diameter semicircle in fair territory.
- At first base, the base has an extension into foul territory 24 in. deep and 24 in. wide.
- Restraining lines running from first to second base and from second to third base, marked 12 ft. from the bases and parallel to the baselines.
- A semicircle restraining line marked in the outfield 100 ft. from home plate and extending to each foul line.

We have included a wheelchair softball field diagram (see Fig. 15.1). The diagram includes the typical dimensions and setup for a regulation wheelchair softball field.

Rules of Play

Wheelchair softball follows the same basic rules of softball as outlined by the ASA for 16 in. softball. However, there are numerous differences between wheelchair and typical softball and many rules that pertain only to wheelchair softball [1]. These are delineated below.

- Players must be in manual wheelchairs with foot platforms.
- In order to tag or touch a base, the baserunner and defensive player must touch the circle surrounding the base with one or more wheels. This can include the two front wheels or caster wheels. Of note, anti-tip casters are not considered a wheel for this purpose. The baserunner may also tag or touch the base with his/her hand.
- If a baserunner is knocked out of his/her chair, he/she may go to an appropriate base without his/her chair as long as he/she does not hop, walk, or run. In this instance, they can make contact with any body part.
- A baserunner may not place or use a lower extremity or someone else's chair to stop his/her chair. If this occurs, the play is dead and results in a dead ball situation.
- A fielder may not advance toward or play the ball when a lower extremity is in contact with the ground.
- The hitter cannot place a lower extremity on the ground when hitting. If this occurs, the ball is dead and the batter is out and all baserunners have to return to the last base achieved.
- The four infielders must have at least one wheel on or inside the infield restraining line until the ball leaves the pitcher's hand. If this is violated, the batter is awarded first base and the play is ruled a walk.
- All outfielders, not including the short fielder, must remain behind the outfield restraining line until the ball leaves the pitcher's hand.
- Lifting is the act of raising the player's buttocks so that both cheeks are no longer in contact with the seating platform or cushion. This is considered an infraction and treated as a delayed dead ball as specified by ASA rules.
- Players classified as quadriparetics are allowed to wear gloves on either hand regardless of position. They are also allowed to alter

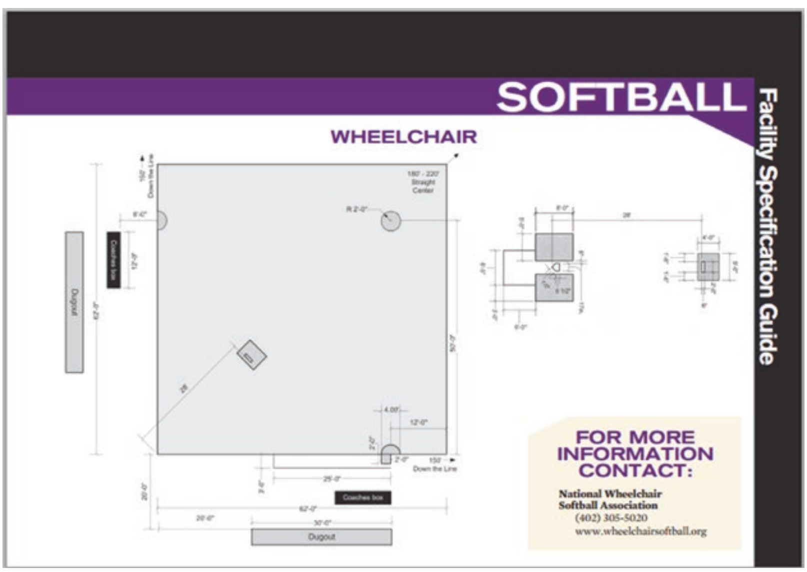


Fig. 15.1 Wheelchair softball field layout. Courtesy of National Wheelchair Softball Association

their bat to improve the grip as long as they clear the altered bat with the head umpire.
- Mitts are allowed to be used by only the catcher and first basemen if they so choose.
- If an overthrow occurs, baserunners may advance a maximum of one base as long as they retouch their original base prior to advancing. They do this at their own risk.
- NWSA rules have a quadriparetic (quad) athlete requirement. The rule states that every team must register at least one quad athlete. If a quad athlete is not registered on a team (or if a quad athlete is registered but does not make it to the game), then that team can only field players with a total value of 19 points, and every tenth batter (or every time the position in the lineup previously scheduled for that quad athlete comes up) is an automatic out. If a team rosters a quad athlete, then the quad athlete has to be in play at all times when on defense. If a team's quad athlete does not take the field, the team has to play defense with only nine fielders.

Equipment

The manual wheelchair is the primary adaptive device the wheelchair softball player uses. It is important to consider the athlete's goals and preferences when choosing the best manual wheelchair design for each player. For example, while higher backrests provide more trunk support, they limit range of motion that athletes would often prefer. All wheelchair softball players are required to have foot plates on their chairs. Many have an additional front bar that stretches from one side of the chair to the other passing in front of the feet to prevent injury to lower limbs during a collision. An important feature of the wheelchair that one should address is the camber of the wheels. Due to the quick turns required when rounding bases and making certain defensive plays, most athletes choose a significant amount of camber to prevent tipping laterally.

Wheelchair softball has unique equipment suited for batting. These devices are supportive wedges that are placed around the wheels of the manual wheelchair to provide stability while the athlete swings the bat (see Pictures 15.2 and 15.3). Some athletes choose to use these blocks, which are often referred to as "sticks" or "cages" by athletes. Others may prefer to stabilize one wheel manually with their hand, while using their free arm to perform a single-arm batting technique to hit the ball.

Softball gloves are also optional pieces of equipment that first basemen and catchers are allowed to use when fielding, but many players opt to play without them given the larger size and lower density of the 16″ softball. Helmet use is not required but in our opinion should be encouraged to reduce the risk of traumatic brain injuries or concussion.

Biomechanics

Wheelchair softball athletes utilize adapted mechanics, when compared to able-bodied athletes, for overhead throwing, underhand pitching, and batting. For both athletes, throwing

Picture 15.2 Variety of batting blocks/cages to help stabilize the wheelchair when batting

Picture 15.3 Batting block/cage in use

begins with the windup and is completed with the follow-through movements occurring after ball release. In able-bodied athletes, the throwing sequence includes kinetic chain movements of the lower limb and trunk to maximize force generation and transfer to the upper limb and hand [3]. During these series of rotational and sagittal movements, body weight transfers from the ipsilateral leg during the windup to the contralateral leg during the follow-through, and the pelvis, initially directed away, rotates towards the player intended to receive the thrown ball. As the acceleration phase begins, pelvic rotation occurs as body weight transfers to the contralateral leg, assisting the throwing arm as it transitions from abduction with external rotation into adduction with internal rotation and ultimately ball release. Similarly, underhand pitching and batting benefit most from the generation of forces created by the leg and core muscles.

In contrast to able-bodied athletes, many wheelchair athletes are not able to use their lower extremities, hip girdle, and other portions of their core musculature to develop force and torque for the throwing and swinging motions required of wheelchair softball. These muscles are also integral to deceleration during the follow-through phases of throwing and batting. Reduction in leg and core muscle control may result in greater eccentric loads on the upper limb and increase the risk of injury [4]. This leads to increased stress on the more peripheral joints such as the shoulder, elbow, and wrist. Instead of developing force for throwing and swinging from the lower limbs, hips, and core, there is increased likelihood of "throwing from the shoulder." Able-bodied athletes are taught not to throw in this manner because this increases risk of injuries to the more peripheral joints. Additionally, while outside the scope of this discussion, the biomechanics of wheelchair propulsion itself creates additional risk for the development of sports-related acute and overuse injuries.

Injuries and Injury Prevention

The popularity of wheelchair softball is growing and with it the need for more clinician awareness of potential injuries that these athletes may experience (see Fig. 15.2). The challenge for the

Head & Face Injuries
Traumatic brain injury
Concussion
Orbital fracture
Nasal fracture
Facial lacerations
Shoulder Injuries
Rotator cuff tendonopathy or tears
Shoulder impingement syndromes
Shoulder labrum injuries
Elbow Injuries
Ulnar collateral ligament
Ulnar neuritis or neuropathy
Cubital tunnel syndrome
Medial epicondylosis
Valgus extension overload syndrome
Stress fracture
Wrist & Hand Injuries
Ulnar mononeuropathy at the wrist
Carpal tunnel syndrome
Fractures
Dislocations
Lower Extremity Injuries
Collision injuries resulting in fracture, soft tissue contusion, and bone contusion
Skin Injuries
Blisters
Abrasions
Lacerations

Fig. 15.2 Wheelchair softball injuries [5, 9, 10, 14, 19–21, 27–31] sports physician is not only appropriately diagnosing and rehabilitating injured athletes but also providing education to participants for injury prevention. Although there are not any accurate incidence rates of wheelchair softball injuries available, they are most likely comparable to or higher than baseball and softball injuries in able-bodied participants. There have been higher reported injury rates among athletes participating in the Winter 2010 and Summer 2012 Paralympic Games than in the respective Olympic Games [5–8]. This included new onset acute injuries totaling 51.5% of the injuries reported during the London 2012 Paralympic Games [5]. Given the increase in Paralympic and adaptive sports participation, there is a great need for sport-specific epidemiological and rehabilitative research for these athletes. Wheelchair softball is a particular topic of tremendous potential and need for additional research given its growth. For wheelchair-using athletes, upper extremity injuries appear to be far more common than lower limb injuries. While there does not appear to be any significant relationship between the incidence of reported injuries and type of disability, adaptive overhead sports are associated with a higher risk of injury development [9].

Musculoskeletal injury assessment includes obtaining a relevant history and thorough evaluation. The most common mechanisms of acute softball injuries are being hit by a ball (20%), collisions with other players (16%), locomotion (11%), and while swinging a bat (3%) [10]. Common softball injuries include fractures, muscle strains, ligament sprains, lacerations, and concussions [10]. Acute and chronic wheelchair sports injuries appear to be near equal in incidence [9, 11]. It is important to understand the athlete's history of similar injuries and potential biomechanical abnormalities in order to prescribe the proper rehabilitation plan. Athletes often desire to return to play as soon as possible, and one study found that 43% of athletes restarted training while still experiencing pain after an injury [12, 13]. Returning to play before resolution of pain may increase the risk of reinjury.

Mild Traumatic Brain Injuries (TBI) and Facial Injuries

Collision between players and being hit by the ball are common mechanisms of injury in softball (see Picture 15.4). They are also the most common ways to sustain a mild TBI and concussion. Being hit by a ball is the mechanism resulting in the most serious softball injuries [10], accounting for 75% and 90% of injuries to the head and face, respectively [14]. To reduce the number of sport-related head injuries, some have suggested helmet use throughout softball games and the use of reduced injury factor (RIF) softballs [10]. Although helmets are not required in wheelchair softball, there is a known benefit to helmet use to limit the incidence and severity of head injury and concussion.

Although softball is considered a low-impact sport, concussions remain a serious concern and contribute to loss of play. Concussions represent 2–3% of baseball injuries with 70% of these injuries occurring during games [9, 15–17]. Similar low-impact wheelchair sports have reported that 6% of athletes have experienced a concussion during play and that 44% of these went unreported with the primary reason being desire to continue play [18]. Often accompanying head injuries are facial injuries such as facial lacerations or facial fractures. For example,

Picture 15.4 The competitiveness and athleticism of wheelchair athletes often leads to collisions and potential for injury as you would expect in any sport, adaptive or otherwise

orbital and nasal fractures are a common cause of softball injuries resulting in emergency department visits [14, 19].

Shoulder Injuries: Rotator Cuff, Labrum, Impingement, Scapular Dyskinesis

Shoulder pain is one of the most common complaints among baseball players [20]. This is a significant concern given that long-term wheelchair use has a well-established relationship with the development of shoulder problems and up to 78% of people with spinal cord injuries experience shoulder pain [21–23]. Interestingly, paraplegic athletes have greater shoulder strength compared to able-bodied athletes [24]. For athletes with shoulder weakness, there is a greater risk for rotator cuff injury [25]. Additionally, the lack of appropriate trunk control is associated with increased shoulder pain in wheelchair athletes that participate in overhead sports [26].

Rotator cuff injuries are common and the prevalence of asymptomatic rotator cuff pathology increases with age [32, 33]. One study found that 63% of manual wheelchair users have a rotator cuff tear compared to 15% of non-wheelchair users [21]. Of these injuries, the supraspinatus tendon appears to be most commonly affected [21, 22]. Overhead wheelchair sports participation results in almost two times higher risk for the development of rotator cuff injury compared to non-sports wheelchair use, and rotator cuff tears in wheelchair athletes are symptomatic 93% of the time [34].

Impingement syndromes are common and are attributed to be the cause of many shoulder problems in people with paraplegia [27]. Rotator cuff impingement may result from either glenohumeral joint instability or from compression of the rotator cuff tendons between the humeral head and overlying acromion, coracoacromial ligament, coracoid, AC joint, or posterior-superior glenoid lip [35]. Muscle imbalances are thought to contribute to shoulder impingement. In particular, relative weakness of the muscles controlling shoulder adduction, internal rotation, and external rotation is considered a culprit [24].

Scapular dysfunction has been considered a contributing factor to the development of shoulder problems [3, 20]. Interestingly, preseason scapular dysfunction does not necessarily predict the development of overhead throwing injuries. In light of this finding, it has been suggested that scapular dyskinesis may be a result of shoulder injury rather than the cause [20]. It remains prudent to use scapular assessments in the evaluation of shoulder injuries and addressing the presence of abnormalities with rehabilitative exercises [3].

The rehabilitation of shoulder injuries has been well described [3, 36, 37]. This should start with accurate diagnosis and then initiating a therapy program to start with proximal segment control including core, hip girdle, and lower extremity strengthening and stability. Scapular and glenohumeral strengthening should be addressed before progressing to dynamic stabilization.

Elbow Injuries

Overhead athletes are prone to developing elbow injuries related to overuse and improper mechanics, with elbow pain reported in up to 70% of baseball players and accounting for 8.8% of reported injuries in the Paralympics [5, 20]. Potential injuries may involve the ulnar collateral ligament (UCL), ulnar nerve (ulnar neuritis or neuropathy), medial epicondyle, common flexor mass, or may result in valgus extension overload syndrome or stress fracture [28]. Cubital tunnel syndrome resulting from ulnar nerve compression at the elbow is the second most common upper limb entrapment neuropathy in athletes and may be caused by traction to the nerve during throwing or from hypertrophy of the wrist flexor muscles, pronator muscle, and medial head of the biceps muscle [29].

Wrist and Hand Injuries

Wrist and hand injuries are among the most common softball-related injuries. One study reports they are the most common cause of softball-injury related emergency department visits [14]. Injuries to the hand may include fractures, dislocations, Mallet fingers, injuries to the flexor tendons and flexor pulleys, ligament strains (including ulnar collateral ligament of the thumb), and muscle sprains [30]. Likewise, wrist injuries may include fracture, strains, sprains, tendonitis, and joint instability [14, 19].

Wheelchair athletes are also susceptible to upper limb nerve entrapments such as median mononeuropathy (carpal tunnel syndrome) or ulnar mononeuropathy at the wrist [31]. Symptoms may include numbness, tingling, burning pain, and weakness along the peripheral nerve distribution. For patients with atypical symptoms, a nerve conduction study with electromyography may be beneficial for diagnosis and guiding an appropriate rehabilitative program.

Lower Extremity Injuries

Lower limb injuries appear to be less common than upper limb injuries in wheelchair sports [12]. Injuries to the foot, ankle, knee, and thigh each represented 6–8% of the injuries sustained during the London 2012 Paralympic Games [5]. Although wheelchair athletes may less frequently develop a lower limb injury, the presence of osteoporosis and paraplegia likely increases the risk of more serious injury such as fracture. The feet may be more susceptible to injury and foot injuries may occur during collisions with other players or during a fall, if the athlete is not adequately secured to their wheelchair.

Skin and Other Soft Tissue Injuries

Soft tissue injuries are the most common injuries in wheelchair athletics, representing one-third of all reported injuries [9]. This may include strains, sprains, bursitis, and tendonitis which are common causes of shoulder, elbow, wrist, and hand pain [9]. Blisters and skin lacerations are also common, accounting for 35% of wheelchair sports injuries [9]. Additionally, prolonged sun exposure may result in sunburns and recommending sunscreen is prudent.

Conclusion

Adaptive sports are gaining in participation and there are approximated to be greater than three million adaptive athletes playing in orgainized sports in the United States [38]. Wheelchair softball is a well-established adaptive sport that has continued to gain popularity over the last 40 years. As the sport's popularity has increased, the need for greater awareness of potential injuries has followed. While the recorded literature is silent on injuries in wheelchair softball, there are common mechanisms and trends we would likely see when considering other wheelchair sports and able-bodied baseball/softball injuries. The clinicians' purpose and goal remains to keep the athletes safe and provide guidance on rehabilitation from sports-related injuries.

Appendix

Muscle Strength Grades

- 0—Total lack of voluntary contraction
- 1—Minimal voluntary contractions without movement of joint; tendon may be palpated to tighten during voluntary contraction
- 2—Voluntary contraction through complete range of motion (ROM) with gravity eliminated
- 3—Voluntary contraction through complete ROM against gravity
- 4—Voluntary contraction through complete ROM against gravity with some resistance
- 5—Voluntary contraction through complete ROM against gravity with full resistance

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16 Wheelchair Dance Sport

Mary Caldwell and Arthur Jason De Luigi

Introduction

Wheelchair dance is most commonly referred to as Wheelchair Dance Sport. (WDS). It is derived from the internationally known able-bodied sport called dance sport. Dance sport, referred to as ballroom dancing in the United States, includes any and all forms of dance. Wheelchair dance first started in Sweden in 1968 for recreational and rehabilitation purposes. By 1998, the first world championship was held, and that same year, it became governed by the International Paralympic Committee (IPC) and the International Paralympic Wheelchair Dance Sport Committee (IPWDSC).

M. Caldwell, DO (✉)
Department of Rehabilitation Medicine,
MedStar National Rehabilitation Hospital,
MedStar Georgetown University School of Medicine,
Washington, DC, USA
e-mail: mary.elena.caldwell@gmail.com

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown
University School of Medicine,
Washington, DC, USA
e-mail: ajweege@yahoo.com

Picture 16.1 Duo Dance event. Picture taken by Alexander Sperl at the 2014 European Championships in Poland. Permission granted for use by the IPC

Rules and Regulations

The rules for WDS are determined by the IPWDSC and complement the rules of able-bodied dance sport as determined by the World Dance Sport Federation (WDSF). There are numerous differences and similarities between dance sport and WDS.

In WDS there are two main event categories and subgroups within each event, as defined in Table 16.1. Within each event category, there are dance subgroups and dance style regulations as listed in Table 16.1.[1]

[1]International Paralympic Committee Wheelchair Dance Sport [Internet]. [cited 2016 Jan 31] [approximately five screens]. Permission for use granted by the IPC. Available from http://www.paralympic.org/wheelchair-dance-sport

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_16

Table 16.1 Type of Wheelchair Dance Sport events (see footnote 1)

A. Conventional events	1. Single dance (one wheelchair user) *Waltz, tango, samba, rumba, or jive* 2. Duo dance (two wheelchair users dance together) *Standard (waltz, tango, Viennese waltz, slow foxtrot, or quickstep) or Latin* 3. Combi dance (when the wheelchair user dances with an able-bodied standing partner) *Standard or Latin (samba, cha-cha-cha, rumba, paso doble, or jive)*
B. Freestyle/showdance events	1. Single dance *Any dance style* 2. Combi dance *Any dance style*

Rules of WDS

The rules of WDS are fully outlined by the IPC in the IPC Wheelchair Dance Sport Rules and Regulations published in August 2015 but will be summarized and reviewed here with the permission of the IPC.[2]

General Rules

Singles participate in either the men or women's section. Dou dance partners and combi dance partners must be made up of one man and one woman, and partners cannot change throughout a competition without certain circumstances. It is possible for Wheelchair Dance Sport athletes to dance in one section or all sections (standard, Latin, or freestyle/showdance). Most importantly, dancers must meet minimum eligibility criteria for WDS.

Movements/Lifts

All movements are allowed, including lifts and acrobatics in freestyle dance, while no lifts (except of only the front wheels or short jumps) are allowed in conventional dance. Dancers are allowed to leave their wheelchairs for transitions only at the beginning or end of the dance. They may not dance on the floor without their wheelchair.

Time Requirements

A minimum of 90 s must occur for waltz, tango, slow foxtrot, quickstep, samba, cha-cha-cha, and paso doble. A minimum of 1 min should occur for the Viennese waltz and jive. In freestyle dance presentations for singles should be between 2 min and 2 min and 30 s. However, the freestyle dance presentation for combi should meet 3 min and 30 s.

Judging

In conventional events, judging is typically based on six categories: aim (focus on the wheelchair athlete), music, movement (including balance and rhythmical control of the wheelchair), choreography, presentation, and charisma. In freestyle events, dancers perform only once, and judging is typically based on technical skills, choreography and presentation, and difficulty level.

Classification Process for Wheelchair Dance Sport Athletes

Only dancers with physical impairments of the lower limbs are eligible to participate in WDS. Most commonly the dancers that participate have cerebral palsy or spinal cord injuries. According to the WDS Classification Rules from March 2014, athletes must meet one of five lower limb impairments in order to participate.[3] These include impairments in both structure and function based on the International Classification of Functioning, Disability, and Health (ICF).

The impairments include:

1. Hypertonia, ataxia, and/or athetosis (with a minimum of Grade 2 on lower limb Modified Ashworth Scale [1] (see Appendix for scale).

[2] IPC Wheelchair Dance Sport Rules and Regulations 2014–2017 [Internet] [cited 2016 Jan 31] [cited full PDF]. Permission for use granted by the IPC. Available from http://www.paralympic.org/sites/default/files/document/150811164904184_Aug+2014+2017+IPC+WDS+Rules+and+Regs.pdf

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Fig. 16.1 Wheelchair Dance Sport classification (see footnote 1)

Functional Tasks

- Wheel control: ability to accelerate and stop the wheel by either hand
- Push function: ability to control wheelchair movement while pushing and while having hand contact with the dance partner
- Pull function: ability to control wheel movement while pulling and while having hand contact with the dance partner
- Full arm rotation: ability to perform a controlled movement of the free arm reaching full extension of the joints and full coordination
- Trunk rotation: ability to fully rotate the trunk without losing balance

Scoring for each task (for each side of body)
2 points for full function
1 point for reduced function
0 points for no function
Maximum Score: 20 points

Less than or equal to 14 points = Sports Class 1 or LWD1 Class
Greater than 14 points = Sports Class 2 or LWD2 Class

2. Impaired muscle power (with a loss of at least ten muscle strength points across the lower limbs according to the Daniels and Worthingham Scale [2] (see Appendix for scale).
3. Impaired passive range of movement of the knee or ankle.
4. Limb deficiency (with the minimum being the absence of ankle joint).
5. Leg length difference (at least 7 cm shortening of leg).

Once eligibility is determined, athletes can then be classified into two groups, Sport Class 1 (LWD 1) and Sport Class 2 (LWD 2). The sport classes are based off the scoring performance in five functional tasks as reviewed in Fig. 16.1 (see footnote 1). Couples can compete in duo dance Sport Class 1 if both athletes are in Sport Class 1 (or if the total score for the athletes is less than 30 points). Couples can compete in duo dance Sport Class 2 if they are both allocated Sport Class 2 (or if their total score is 30 points or more).

Picture 16.2 Combi dance. Picture taken by Alexander Sperl at the 2014 European Championships in Poland. Permission granted for use by the IPC

Equipment

Wheelchairs

Dance sport athletes can use manual or electric wheelchairs. The manual wheelchair design can vary, but it is typically five wheeled (two swivel casters in the front, two drive wheels, and one swivel caster in the back). The two swivel casters in the front are associated with a footplate to secure the dancer's feet. The design of the wheelchair allows the dancer to have control of the chair with smooth transitions and to prevent tipping. Depending on the athlete and dance style, some athletes may have no swivel casters on the chair to allow for specific maneuvers to be incorporated into the dance.

Dance Floor

The surface of the dance floor should be at least 250 square meters, with no side of the floor less than 10 m in length. World Championship and Regional Championship floors must be 350 square meters (see footnote 1).

Biomechanics

Ballroom dancing requires fast as well as turns and changes of direction that require sensory stimulation, motor coordination, and creativity [3]. WDS athletes, like able-bodied dancers, must incorporate body aspects (posture, alignment, flexibility, body control, and balance), dynamic aspects (strength and stability), and presentation aspects (confidence, style, and charisma) into a performance. Balance and strength are two of the key ways WDS athletes must use adapted mechanics compared to able-bodied dancers in order to perform.

Recall that balance requires a complex interaction between the visual, vestibular, and nervous system [3]. Able-bodied dancers maintain balance within the complexity of their dance by adjusting their legs, pelvis, and trunk quickly and subtly before the onset of arm movements [4]. They rely on muscle synergy patterns that occur milliseconds before movements. Such whole body reactions support limb movements without excessive disturbance to the center preventing the appearance of swaying or instability [5]. WDS athletes, who cannot use their lower limb movements for balance, must instead maintain balance with their wheelchair, trunk, and upper body. In order to accomplish balance, like many of the wheelchair sports and especially important for dancers, proper alignment of center in the wheelchair with seat positioning, wheel alignment, and hand rim configurations are key [6, 7]. Trunk strength is then heavily needed not only for creating stability during arm movements but also for maintaining posture throughout the performance and in deceleration [8].

Similar to the able-bodied dancer, upper body strength is also very important for WDS athletes for maintaining contact with their dance partner, performing arm and hand positions, and controlling their chair [9]. In contrast to the able-bodied dancer, the wheelchair dancer is unable to use the whole body kinetic chain in maintaining contact with their partner, and this may lead to greater eccentric load on the upper body making the wheelchair athlete more prone to upper body injury [10]. The WDS athlete must also propel the wheelchair in a controlled and stylistic fashion as they will be judged on their ability to control chair movements (see footnote 2). Shoulder strength and range of motion is key in all of these movements. For example in order to lift the front of the chair in a dance, wheelchair users rely heavily on shoulder flexors and internal rotators to generate the greatest force, while elbow flexors are required to control the shoulder efforts and maintain balance within the chair [11]. Improper technique and training could lead to injury of these muscles affecting not only performance but also everyday function in these athletes.

Picture 16.3 Combi dance with an example of posture, balance, and technicality of the dancing. Picture taken by Alexander Sperl at the 2014 European Championships in Poland. Permission granted for use by the IPC

Common Injuries and Injury Prevention

There is unfortunately no specific incidence data on WDS injuries, but literature is available from able-bodied dance sport and other wheelchair athletes. Therefore, common wheelchair athlete injuries will be reviewed first and compared to that of able-bodied dance sport. Figure 16.2 reviews the common injuries reported in wheelchair athletes without sport specification.

Fig. 16.2 Common wheelchair sport injuries

Upper Limb Injuries

Shoulder (15-72% of reported injuries)
-Largely muscle strains, tendinopathies, bursitis
Hand(~20%)/Fingers (~11%)/Arm (~10%)
-Tendinopathies, ligament strains, muscle strains, nerve entrapments (median mononeuropathy at the wrist and ulnar mononeuropathy at the elbow)

Soft Tissue Injuries

Commonly of limbs
-Blisters, lacerations, abrasions, pressure ulcers (~30% of reported injuries)

Spine Injuries

Possibly related to posture
-Muscle spasms, sprains

Lower Extremity Injuries

Less likely to have fractures or contusions without collision, but may occur related to impairments specific to each athlete

Common Wheelchair Athlete Injuries

Upper Limb Injuries

In general for wheelchair sports, upper limb injuries are most commonly reported. A 1991 study reported injuries commonly occurred in the hand (20%), followed then by the shoulder (15.5%), fingers (11.1%), and arm (10%) [12]. Another study, looking at only wheelchair athletes in track and field, wheelchair basketball, quad rugby, fencing, table tennis, tennis, and volleyball, similarly demonstrated soft tissues injuries commonly occurring in the shoulder (18%), followed by the arm (12%) and the wrist (12%) [13]. The general consensus within the adaptive sport literature is that injuries most commonly involve the shoulder, ranging between 15 [12] and 72% with the highest incidence in female wheelchair basketball players [14–16]. In those with arm injuries, the most likely diagnosis was muscle strains (52%), tendinopathy (30%), bursitis (15.6%), and contusions [12, 13]. Interestingly, a 2012 Summer Paralympic study, which included all adaptive athletes (wheelchair and non-wheelchair users), determined that irrespective of impairment type, the upper limb accounted for 50.2% of all injuries, with shoulder being most common (17.7%), followed by the wrist/hand (11.4%) and elbow (8.8%) [17, 18].

In wheelchair athletes, it appears chronic injuries (35–60%) may be more likely than acute, but this could be sport and study specific depending on the definition of acute versus chronic and methods to collect data [19–21]. Upper limb nerve entrapments are also common, specifically median mononeuropathy (50%) at the wrist and ulnar neuropathy (25%) at the wrist [22].

Spine Injuries

While the shoulder may be the most common site of reported pain in wheelchair athletes, the actual site of pathology in one study was determined to be the cervical and thoracic spine (59 and 8%, respectively), suggesting common referral of pain to the shoulder [14]. This stresses the importance of a thorough physical examination.

Soft Tissue Injuries

Soft tissue injuries are often reported to include sprains, strains, and tendinopathies of the shoulder, elbow, arm, and hand, as well as blisters (74%) abrasions (68%), lacerations (12%), and decubitus ulcers (8.9%) [12]. Another study reported blisters and skin lacerations accounting for up to 35% of reported injuries [19]. Recall that the likely mechanism of blisters, abrasions, and lacerations (when there is not a collision involved) is contact of the hand or wrist with the chair rim. Since these may require minimum medical care, they may even be under reported [23].

Lower Extremity Injuries

The lower extremity incidence of injury is less common than the able-bodied population in wheelchair athletes [24]. Lower extremity fractures are more common in high speed adaptive sports with collision like wheelchair basketball, rugby, and softball [23] than would likely occur in Wheelchair Dance Sport.

Injury Prevention for Wheelchair Sports (General)

All athletes should undergo a thorough physical examination and a task-specific performance evaluation to help identify areas prone to excessive load [25, 42].

In general, since wheelchair athletes are more likely to develop upper limb injuries, it is not unreasonable to address range of motion and strengthening of the upper body. This includes the upper back, shoulder, and scapular muscles in all wheelchair athletes [26, 27]. Injuries in the upper limb may be due to the repetitive use of the upper extremities for wheelchair propulsion and overhead activities (in both every day life and sport). For example, repetitive wheelchair propulsion mechanics encourage repetitive protraction of the scapula, leading to altered posture, weaker scapular stabilizers, and tightening of anterior shoulder muscles [28]. This may place the upper limb at increased risk for microtrauma and subsequent overuse injuries, like rotator cuff tears [29]. It may also increase the risk for other arm injuries, like tendinopathies, while performing less common movements that are sport specific [30]. The wheelchair athlete with scapulothoracic dyskinesis could also have an increased risk of shoulder impingement [30]. The "lack" of the entire kinetic chain during sport-specific tasks (like with racquet sports and throwing sports), and its role with regard to injuries, likely varies per wheelchair sport [10, 31].

The physician should also make sure that shoulder injuries are prevented "off the court." For example, there is already a higher incidence of rotator cuff tears in wheelchair users compared to non-wheelchair users, which may mean the wheelchair athlete is at even higher risk for rotator injuries [32, 33]. In order to prevent injuries "off the court," transfers and wheelchair propulsion should be monitored if applicable [34]. Physical therapy or occupational therapy should be considered for athletes who are at risk for injuries due to poor range of motion and improper technique seen with everyday functional tasks.

To expand on wheelchair ergonomics, assessment of the wheelchair in use may also help identify risk for nerve entrapments and spine injuries [6]. For example, nerve entrapments are likely secondary to hand rim mechanics causing repetitive trauma to the nerves at the wrist or elbow [22]. It would not be unreasonable to consider orthotics as needed to try and prevent such entrapments. The spine may also be at risk for injury due to atypical seating position in wheelchair athletes. For example, spinal cord athletes typically sit with a posterior pelvic tilt, increased kyphosis of the thoracic spine, and demonstrate a head forward position [30]. This may place inappropriate stress on the spine and lead to microtrauma and degeneration within the spine. All wheelchair modifications that can be made, without violating chair guidelines within each sport, should be considered. It would also be reasonable to address core strength and spine strength in these athletes if possible.

Lastly, spinal cord athletes and cerebral palsy athletes have independent patterns of meeting energy demands during exercise (may not be anaerobic sources for power), and it is recommended that each strengthening program (such as intensity and frequency) be tailored toward the individual athlete's impairments [35]. For sport-specific injury prevention, please refer to individual sections when available.

Able-Bodied Dance Sport Injuries

Studies for able-bodied dance sport have demonstrated that the lower extremity is reported to account for 20–70% of reported injuries [9, 36–38]. In dance sport, the spine is reported to account for 12–25% of reported injuries [9, 37]. This is similar to most common injuries reported for all dancer [39]. The upper extremities were reported as injured less frequently, with the most common injury being the shoulder [9, 40]. Blockages (such as vascular), pulled muscles, and contusions were the most commonly reported injuries [9]. Most dancers felt that the cause of injury was from repetitive movements or chronic fatigue and overwork [36]. Given the dancers in WDS do not use their lower limbs, WDS athletes would not be expected to have the same location and causes of injury (although this study has not been performed).

Injury Prevention in WDS

Like other forms of similar dance sports, for instance, gymnastics, figure skating, and concert dance, dancers place their bodies under high physiological and psychological demands. There is no specific literature for injury prevention in WDS, and therefore injury prevention strategies in able-bodied dance sport will be referenced here. It has been proposed that in order to best prepare dancers for the sport and prevent injuries, that dancers should participate in macro-cycle periodization planning, aerobic and anaerobic conditioning, range of motion and muscular endurance training, and performance psychology methods [41]. Further, athletes should warm up and cool down, not work in an unsuitable environment, and the dancer should receive immediate treatment for injuries once they occur [36].

Summary

Wheelchair Dance Sport is an exciting and beautifully technical sport whose popularity is growing worldwide and nationwide. It is offered in many states throughout the United States for wheelchair users of all ages. As the sport continues to grow, medical providers should be aware that the athletes must have lower limb impairments and that athletes are classified into two classes based on a series of functional tasks in their wheelchair. The exact epidemiology of injuries in WDS has not been studied directly, but literature regarding common injuries in the wheelchair athlete is available, and the upper limb is the most commonly injured site. Lastly, the sport is truly an art requiring balance and range of motion of the dancers to master technique and performance.

Appendix

Modified Ashworth Scale [1]

0: No increase in muscle tone
1: Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion when the affected part(s) is moved in flexion or extension
1+: Slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the reminder (less than half) of the ROM (range of movement)
2: More marked increase in muscle tone through most of the ROM, but affected part(s) easily moves
3: Considerable increase in muscle tone passive, movement difficult
4: Affected part(s) rigid in flexion or extension

Daniels and Worthingham Scale [2]

5: (Normal) Holds test position against maximal resistance
4+: Holds test position against moderate to strong pressure
4: (Good) holds test position against moderate resistance
4−: Holds test position against slight to moderate pressure
3+: Holds test position against slight resistance
3: (Fair) Holds test position against gravity
3−: Gradual release from test position
2+: Moves through partial ROM against gravity OR moves through complete ROM gravity eliminated and holds against pressure
2: (Poor) Able to move through ROM gravity eliminated
2−: Moves through partial ROM gravity eliminated

1: (Trace) No viable movement; but palpable or observable tendon prominence/flicker contraction
0: No activity or no palpable or observable muscle contraction

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Wheelchair Fencing

17

Mary Caldwell and Arthur Jason De Luigi

Introduction

Wheelchair fencing is an exciting and ballistic-like sport, which involves technique, power, speed, strength, and coordination. Wheelchair fencing was one of the first Summer Paralympic Games. It was originally presented at the International Stoke Mandeville Games in 1954 and quickly gained popularity. An overview of the competition, athlete classification system, equipment, and common injuries seen will be reviewed.

Rules and Regulations

Wheelchair fencing rules and regulations are governed by the International Wheelchair and Amputee Sports Federation (IWAS), a federation of the International Paralympic Committee (IPC). Able-bodied fencing and wheelchair fencing share very similar rules and regulations, but there are important differences regarding holding the weapon, maintaining balance in the wheelchair, and common injuries.

A review of the wheelchair fencing rules is provided here based on the International Wheelchair Fencing (IWF) Rules for Competition, Book 1-Technical Rules [1]. These rules are meant to give a basic understanding of the wheelchair fencing and may change as determined by the IWF. To review these rules in their complete and updated form, refer to the IWF website.

Common Competition Rules

Competitions within wheelchair fencing are divided by weapon type (foil, sabre, or epee), sex, athlete category (A, B, or C), age, and further if the fencer is competing as individual or as a team. Men and women compete in foil and epee within their gender category, while only men participate in sabre [1].

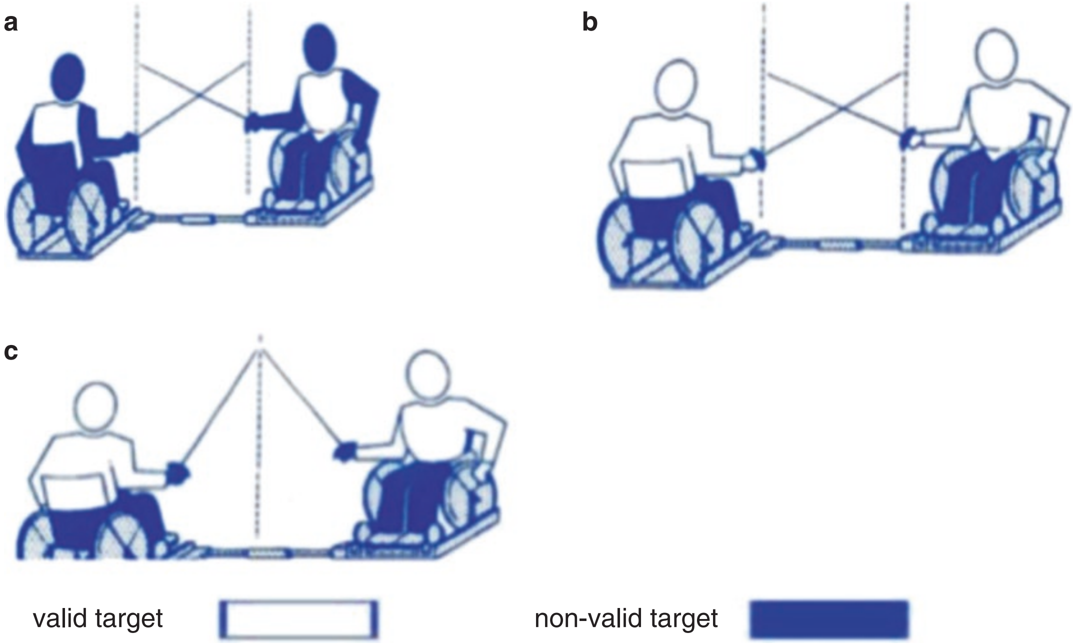
There are several offensive actions within fencing, and they include the attack, riposte, counter-riposte, the remise, the redoublement, reprise of the attack, and counter-time. Similarly, there are multiple actions a fencer can use in defense called parries (simple, direct, or circular parries) [1].

The match between two fencers is commonly called a “bout.” The duration of a bout varies depending on the event [1]. There are typically two parts to individual events, the pools and the direct eliminations. In pools, every fencer competes

M. Caldwell, DO (✉)
Department of Rehabilitation Medicine,
MedStar National Rehabilitation Hospital,
MedStar Georgetown University School of Medicine,
Washington, DC, USA
e-mail: mary.elena.caldwell@gmail.com

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown
University School of Medicine,
Washington, DC, USA
e-mail: ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_17



Picture 17.1 A–C: Valid targets for (**a**) foil, (**b**) epee, and (**c**) sabre [2]. Permission for use granted by IWAS (©IWAS)

against the other fencers at least once. The duration of a bout for pools is five hits and lasts a maximum of 3 min [1]. For direct elimination bouts, the bout lasts 9 min divided into three, 3 min periods (with 1 min in between periods) or for 15 hits. In team events, there are 3 min for each bout or lap [1].

The judging of hits in adaptive fencing is essentially the same as in able-bodied foil, epee, and sabre. In foil and epee points are only scored by the blade. In foil, the fencer may target the neck, torso, back, and groin (not the arms or legs) [2] (Picture 17.1A). Whereas, in epee the head, arms, body, and both hands are valid targets (not the legs) [2] (Picture 17.1B). In sabre, hits with the blade or point are valid, and the whole body above the waist, except the weapon hand, is a valid target [2] (Picture 17.1C).

Holding the Weapon

The hand cannot leave the weapon handle or slip along the handle during an offensive action [1]. If a special device or attachment is on the handle, or there is a special shape to the handle, the upper surface of the thumb must be in the same plane as the grove in the blade (at foil or at epee) and perpendicular to the plane of flexibility at the blade of sabre [1]. The weapon must be used with one hand only, and the fencer cannot change hands until the end of a bout, unless the referee gives special permission, for example, due to injury [1]. Fencers with loss of grip or poor strength in weapon hand may bind the weapon to their hand with the approval of two IWF classifiers [1].

On Guard: Beginning, Stopping, and Restarting a Bout

Competitors are always put on guard in the upright position (sitting upright in the center of the width of their chairs) [1]. The referee will order "On Guard!" and then asks "Are you ready?". Without any objections, the command "Play!" is given. A bout stops on the word "Halt!". This may occur if one of the competitors is disarmed and loses balance or if the fixation of a wheelchair or ground cable to the epee aprons is unfastened [1].

Lifting from the Chair and Balance

A fencer's foot cannot leave the wheelchair footrest or use the floor to gain advantage during play [1]. A fencer cannot leave the wheelchair seat except one buttock off the seat is allowed [1]. If a fencer loses balance or becomes unfastened in the chair, "Halt!" is called. Importantly, a hit scored before balance is lost is valid [1].

Stoppage: Wheelchair Damage and Injuries

If wheelchair damage occurs, the referee allows a maximum of 10 min to fix the chair. If the fencer cannot continue to fight, the referee will determine if the fencer should retire (in individual event) or be replaced (in team event) [1].

If a disability-related event occurs (such as a muscle spasm), the referee may allow time for recovery (without time restrictions) but also must be sure athletes are not taking unfair advantage of this [1]. If an injury occurs during a bout and is properly assessed by an IWF delegate or physician, the referee can allow a 10 min break for evaluation [1]. After evaluation and treatment of that injury only, the doctor will determine if the athlete should continue [1]. That fencer should not have another break during that day, unless another and different injury occurs [1]. If the fencer cannot finish a bout due to injury, they can still participate in other bouts that day, but only if given permission by the physician [1].

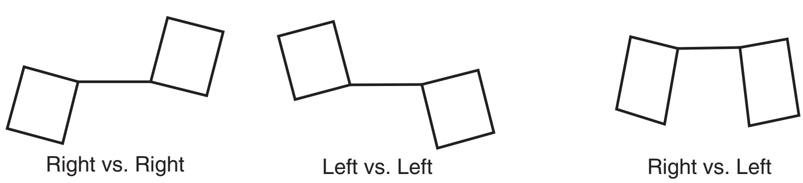
Field of Play

The field of play on which all wheelchair fencing competitions occur is called a piste. It is an even surface with a fencing frame on it for the fixation of the two wheelchairs to the piste. The frame must be arranged in a way to enable fencers to fence with their preferred fencing arm [2] (Picture 17.2). There is also a ratchet strap that secures the front of the chair so it will not tip [1]. The distance between the fencers on the piste is determined prior to the start of the match using each player's arm length with weapon in hand [1]. In the case of fencers with unequal arm length, the fencer with the shorter arm may chose a distance that lies in between his and his opponent's distance. Fencers with restricted arm movements (within Category C) will determine the measure by reaching a point 10 cm beyond the inner forearm for foil or 10 cm inside the outer edge of the elbow for sabre and epee [1].

Equipment

Wheelchair

The wheelchair back and seating can be rigid or flexible [2]. The wheelchair can be a maximum of 53 cm from the floor to the seat rail, and it cannot exceed 3 cm from the fencer's hip when they are in the center of the wheelchair. The back of the wheelchair must be a minimum height of 15 cm from the seat of the wheelchair or the cushion when the fencer is sitting on it. It must be 90° to the horizontal. If the fencer requires the need for a different material or different angle for the back of the wheelchair, it must be pre-approved [2]. A



Picture 17.2 Example of wheelchair fencing positions to allow for right versus right, left versus left, right versus left fencers [2]. Permission for use granted by IWAS (©IWAS)

side-guard cannot be used on the fencing arm side of the wheelchair. The side-guard on the non-fencing arm must meet a minimum height from the seat of the chair and minimum length from the back of the chair, available for review from the materials handbook [2]. If a cushion is used, it cannot be rigid or wedge shaped and must have an even thickness [2]. Camber may be added to the wheels to facilitate turning; however, the wheels must fit within the fencing frames [2]. Fencers can elect to use a grab handle for the unarmed hand [2]. Belts can be used to fasten the legs or unarmed hand, as long as it is not elastic and does not cover the valid target [2]. For athletes with deficiency of a lower limb, the prosthetic legs must be removed for competitions [2].

Weapons

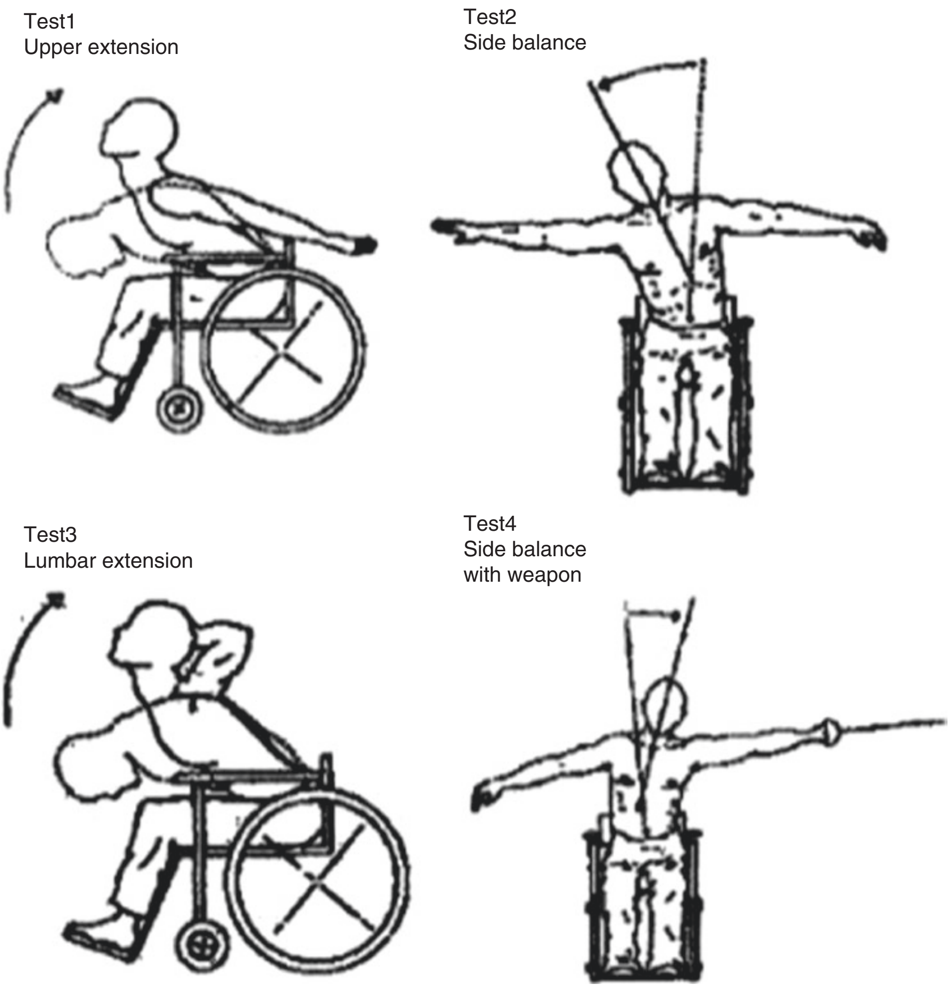
Recall that there are three weapon categories: foil, sabre, and epee. The foil is a thrusting weapon and is a maximum weight of 500 g [2]. Epee is also a thrusting weapon, like the foil, but heavier (maximum weight 770 g) [2]. Sabre utilizes a light cutting and thrusting weapon and the maximum weight of the sabre is 500 g [2]. For specific information on weapons, gloves, masks, bodywire, and jackets, reference the IWF Rules for Competition, Material Rules [2].

Classification Process for Wheelchair Fencing

Athletes that participate in wheelchair fencing must have lower limb impairments. Commonly athletes have spinal cord injuries, cerebral palsy, or limb deficiency (congenital or amputations). Athletes must undergo a series of functional and technical tests (Fig. 17.1, Picture 17.3) in order to be placed into one of five sports classes that is further subdivided into three categories (A, B, and C) Fig. 17.2 [3]. There is also "Bench Testing" available for fencers with spinal disabilities, fencers with spasticity, athetosis and dystonia, and orthopedic injuries that may result in lack of range of motion [3].

Test 1	Dorsal muscles are tested. The athlete is forward flexed and seated in the wheelchair with arms retroflexed and tries to return to upright position
Test 2	The athlete is tested on lateral balance and must lean laterally to right and left with arms abducted.
Test 3	Extension of the trunk, specifically lumbar muscles. Repeat Test 1, but with hands on the back of the neck.
Test 4	Repeat Test 2, but now with the weight of the weapon
Test 5	Evaluates trunk movement half way between test 1 and 3 and test 2 and 4 and now the fencer can hold the wheelchair with the opposed limb.
Test 6	Similar to Test 1, but executed with the leaning forward at 45°.
Points: 0- No function 1- Very weak execution, minimum movement 2- Weak execution, fair movement 3- Normal execution	

Fig. 17.1 Adaptive fencing athlete classification tests [3]. Functional tests (refer to Picture 17.3)



Picture 17.3 Functional tests for adaptive fencers [3]. Permission for use granted by IWAS (©IWAS)

Category C - Class 1A	Athletes with no sitting balance and impaired playing arm with no elbow extension verse gravity and no residual function of the hand (the weapon must be secured with a bandage). Comparable to athletes with spinal lesions at C5/C6.
Category C - Class 1B	Athletes without sitting balance and affected fencing arm with functional elbow extension but no functional finger flexion (bandage use to secure weapon). Comparable to athletes with C7/C8 level or higher incomplete lesion.
Category B - Class 2	Fair sitting balance and normal fencing arm. (Functional Tests 1 and 2do not total more than 4 points.) Comparable to T1-T9 paraplegics or incomplete paraplegics.
Category A - Class 3	Good sitting balance, without support of legs and normal fencing arm. Functional tests 1 and 2 with point score 5 to 9. Subjects with double above the knee amputations. Comparable to T10-L2 paraplegics or incomplete lesions above T10.
Category A - Class 4	Good sitting balance without support of legs and normal fencing arm. Comparable to spinal cord lesions below L4. Functional Tests 3 and 4 total at least 5 points.
Note: Observation is recommended of the person fencing as well in the case of doubt.	

Fig. 17.2 Fencing sport classes [3]

Biomechanics

There are no definitive studies on the specific biomechanics of wheelchair fencers in the offensive and defensive positions compared to able-bodied fencers. Studies in able-bodied fencers typically focus on the lunge and lower body mechanics with regard to performance, which would not apply to the wheelchair fencers [4]. Wheelchair fencers rely strictly on their upper body and trunk for competitions. One could speculate that the repetitive asymmetrical activity of wheelchair fencers could lead to upper body functional asymmetry, similar to that seen in able-bodied fencers [5]. Between this asymmetry and poor trunk control (lack of the kinetic chain), the upper extremity shoulder girdle and scapular muscles may be prone to overuse injuries [4]. This may be a contributing factor to why wheelchair fencers have frequent injuries to their upper limbs [4].

Common Injuries and Injury Prevention

Common Wheelchair Athlete Injuries

Common wheelchair athlete injuries are summarized in Fig. 17.3 and expanded on in this section. For review of studies looking at injuries specific to wheelchair fencers, see section "Wheelchair Fencing Injuries" in this chapter.

Upper Limb Injuries

In general for wheelchair sports, upper limb injuries are most commonly reported. A 1991 study reported injuries commonly occurred in the hand (20%), followed then by the shoulder (15.5%), fingers (11.1%), and arm (10%) [6]. Another study, looking at only wheelchair athletes in track and field, wheelchair basketball, quad rugby, fencing, table tennis, tennis, and volleyball, similarly demonstrated soft tissues injuries commonly occurring in the shoulder (18%), followed by the arm (12%) and the wrist (12%) [7]. The general consensus within the adaptive sport literature is that injuries most commonly involve the shoulder, ranging between 15 [6] and 72% with the highest incidence in female wheelchair basketball players [8–10]. In those with arm injuries, the most likely diagnosis was muscle strains (52%), tendinopathy (30%), bursitis (15.6%), and contusions [6, 7]. Interestingly, a 2012 Summer Paralympic study, which included all adaptive athletes (wheelchair and non-wheelchair users), determined that irrespective of impairment type, the upper limb accounted for 50.2% of all injuries, with shoulder being most common (17.7%), followed by the wrist/hand (11.4%) and elbow (8.8%) [11, 12].

In wheelchair athletes, it appears chronic injuries (35–60%) may be more likely than acute, but this could be sport and study specific depending on the definition of acute versus chronic and methods to collect data [13–15]. Upper limb nerve entrapments are also common, specifically median mononeuropathy (50%) at the wrist and ulnar neuropathy (25%) at the wrist [16].

Spine Injuries

While the shoulder may be the most common site of reported pain in wheelchair athletes, the actual site of pathology in one study was determined to be the cervical and thoracic spine (59 and 8%,

Upper Limb Injuries	Shoulder (15-72% of reported injuries) -Largely muscle strains, tendinopathies, bursitis Hand (~20%)/Fingers (~11%)/Arm (~10%) -Tendinopathies, ligament strains, muscle strains, nerve entrapments (median mononeuropathy at the wrist and ulnar mononeuropathy at the elbow)
Soft Tissue Injuries	Commonly of limbs -Blisters, lacerations, abrasions, pressure ulcers (~30% of reported injuries)
Spine Injuries	Possibly related to posture -Muscle spasms, sprains
Lower Extremity Injuries	Less likely to have fractures or contusions without collision, but may occur related to impairments specific to each athlete

Fig. 17.3 Common wheelchair sport injuries (For references, please refer to text)

respectively), suggesting common referral of pain to the shoulder [8]. This stresses the importance of a thorough physical examination.

Soft Tissue Injuries

Soft tissue injuries are often reported to include sprains, strains, and tendinopathies of the shoulder, elbow, arm, and hand, as well as blisters (74%) abrasions (68%), lacerations (12%), and decubitus ulcers (8.9%) [6]. Another study reported blisters and skin lacerations accounting for up to 35% of reported injuries [13]. Recall that the likely mechanism of blisters, abrasions, and lacerations (when there is not a collision involved) is contact of the hand or wrist with the chair rim. Since these may require minimum medical care, they may even be under reported [17].

Lower Extremity Injuries

The lower extremity incidence of injury is less common than the able-bodied population in wheelchair athletes [18]. Lower extremity fractures are more common in high speed adaptive sports with collision like wheelchair basketball, rugby, and softball [17].

Common Wheelchair Fencing Injuries

Wheelchair fencers are most likely to injure their upper body [4]. Willick et al. found that chronic injuries were 1.4 times more common than acute in wheelchair fencing [11]. Willick et al. also reported an injury incidence rate of 18 injuries per athlete days (overall incidence rate 12.7) [11]. In a 1992 Paralympic study, 71% of wheelchair fencers acquired an injury during training or competition [19].

A 2012 prospective study compared able-bodied fencers to wheelchair fencers. Wheelchair fencers acquired a higher percentage of upper extremity injuries (73.8%). The most common wheelchair fencing injury was elbow strain (32.6%) and shoulder strain (15.8%). Among wheelchair fencers, Category A fencers had a higher risk of muscle strain and shoulder injury compared to Category B fencers. Sprains occurred in 28.4% athletes, most commonly in the lumbar spine, shoulder, and cervical spine [4].

Significant fencing-specific injuries, such as punctures or lacerations, are very rare but can occur [20, 21]. Major injuries, such as partial-thickness tendon tears of the shoulder (4.2%), have also been reported in wheelchair fencers [4].

As discussed previously, for other common wheelchair sport injuries, in which studies were not specific to fencing but may have included fencing, see Fig. 17.3.

Able-Bodied Fencing Injuries

Able-bodied fencing injuries are very different when compared to wheelchair fencing injuries. For example, contrary to wheelchair fencing, the leg is one of the most commonly injured sites (60–69% of injuries) [4, 21, 22], and only 16.1% of fencers report shoulder injuries [4]. Strains (26.1%) and sprains (25.5%) are the most common in the knee (19.6%), thigh/hamstring (15.2%), and ankle (13%) [22]. This is likely due to the biomechanics involved with lunging in able-bodied fencing, which would not apply to wheelchair fencers [4]. Soft tissue injuries (blisters, contusions, abrasions) were also reported frequently in able-bodied fencers [21].

Injury Prevention in Wheelchair Fencing

There is no literature specific for injury prevention in wheelchair fencing, and therefore injury prevention in able-bodied fencing will be referenced. Fencing is a highly "explosive" sport that relies predominately on anaerobic sources for power and speed. Athletes must be able to compete and perform without muscle fatigue in order to prevent injuries [23]. In order to prevent injuries and pain, fencers should strengthen the upper body, including the upper back, shoulder, and scapular muscles if possible [23, 24]. Therefore, it is important to review general injury prevention strategies in wheelchair sports.

Injury Prevention for Wheelchair Sports (General)

All athletes should undergo a thorough physical examination and a task-specific performance evaluation to help identify areas prone to excessive load. [25] [36].

In general, since wheelchair athletes are more likely to develop upper limb injuries, it is not unreasonable to address range of motion and strengthening of the upper body. This includes the upper back, shoulder, and scapular muscles in all wheelchair athletes [23, 24]. Injuries in the upper limb may be due to the repetitive use of the upper extremities for wheelchair propulsion and overhead activities (in both every day life and sport). For example, repetitive wheelchair propulsion mechanics encourage repetitive protraction of the scapula, leading to altered posture, and tightening of anterior shoulder muscles [26]. This may place the upper limb at increased risk for microtrauma and subsequent overuse injuries, like rotator cuff tears and tendinopathies [27, 28]. The "lack" of the entire kinetic chain during sport-specific tasks (like with racquet sports and throwing sports), and it's role with regard to injuries, likely varies per wheelchair sport [29, 30].

The physician should also make sure that shoulder injuries are prevented "off the court." For example, there is already a higher incidence of rotator cuff tears in wheelchair users compared to non-wheelchair users, which may mean the wheelchair athlete is at even higher risk for rotator injuries [31, 32]. In order to prevent injuries "off the court," transfers and wheelchair propulsion should be monitored if applicable [33]. Physical therapy or occupational therapy should be considered for athletes who are at risk for injuries due to poor range of motion and improper technique seen with everyday functional tasks.

To expand on wheelchair ergonomics, assessment of the wheelchair in use may also help identify risk for nerve entrapments and spine injuries [34]. For example, nerve entrapments are likely secondary to hand rim mechanics causing repetitive trauma to the nerves at the wrist or elbow [16]. It would not be unreasonable to consider orthotics as needed to try and prevent such entrapments. The spine may also be at risk for injury due to atypical seating position in wheelchair athletes. For example, spinal cord athletes typically sit with a posterior pelvic tilt, increased kyphosis of the thoracic spine, and demonstrate a head forward position [28]. This may place inappropriate stress on the spine and lead to microtrauma and degeneration within the spine. All wheelchair modifications that can be made, without violating chair guidelines within each sport, should be considered.

Lastly, spinal cord athletes and cerebral palsy athletes have independent patterns of meeting energy demands during exercise (may not be anaerobic sources for power), and it is recommended that each strengthening program (such as intensity and frequency) be tailored toward the individual athlete's impairments [35].

Summary

Athletes that participate in wheelchair fencing must have lower limb impairments. Players are classified into five classes based on sitting balance, fencing arm impairments, and functional tasks if necessary. Players commonly have spinal cord injuries, cerebral palsy, or amputations. There are three categories (A, B, or C) for each competition event (foil, sabre, or epee) based on the five athlete classifications. Understanding the repetitive movements required of the wheelchair fencing athlete is key for the medical provider in preventing and treating injuries. The clinician must also remember that injuries in wheelchair fencing are different than the common injuries seen in able-bodied fencing. Lastly, this sport requires an in depth understanding of the adaptive equipment to be utilized, as it must meet the approved rules and regulations of the IWF before use in competition.

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Wheelchair Curling

18

Mary Caldwell and Arthur Jason De Luigi

Introduction

Wheelchair curling is both a recreational and a Winter Paralympic sport. It is also one of the most affordable wheelchair sports as minimal additional sports equipment is required. It is a sport similar to chess as it is a game of tactics, concentration, and calculation. This section will discuss the equipment, rules and regulations, athlete classification, biomechanics, and common injuries as pertinent to wheelchair curling (Picture 18.1).

Equipment

The Sheet

Wheelchair curling is played on an ice surface called a "sheet" (Picture 18.2). The sheet has parallel lines on it: the tee line, the back line, the hog line, the center line, the hack line, and the courtesy line. Where the tee line and center line intersect is called the "tee." With the tee as the center, four concentric circles surround it, and this entire area is called the house.[1] In wheelchair events, there are two wheelchair lines between the hog lines and the outermost circle. Wheelchair users typically set their chair in front of the house on the delivery end, about 8–10 feet back from the hog line, instead of using the hack at the delivery end of the sheet (see footnote 1).

Stones

The stones are made of granite and are concave on the upper and lower surfaces (see footnote 1). A handle is bolted into the stone and is channeled through the other side. A delivery stick can be used in wheelchair curling to deliver the stone via the handle (instead of the hand) and can be borrowed from the curling facility typically. Other athletes chose to use their hand to deliver the stone instead of the stick. The stones are delivered from one side to the house of the other side (see footnote 1).

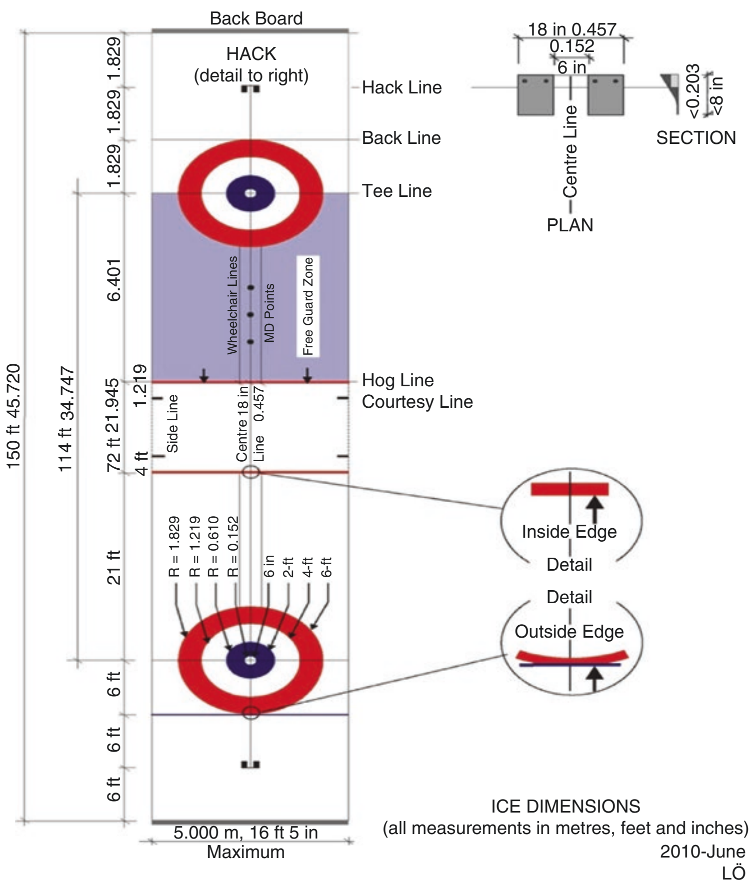
M. Caldwell, DO (✉)
Department of Rehabilitation Medicine,
MedStar National Rehabilitation Hospital,
MedStar Georgetown University School of Medicine,
Washington, DC, USA
e-mail: mary.elena.caldwell@gmail.com

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown
University School of Medicine,
Washington, DC, USA
e-mail: ajweege@yahoo.com

[1]WCF: The Rules of Curling, October 2015. [Internet] [cited 2016 March 9]. [Full PDF]. Available from: http://www.worldcurling.org/rules-and-regulations-downloads. Permission for use granted by the World Curling Federation

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_18

Picture 18.1 Curling action from the World Wheelchair Curling Championship 2016. ©World Curling Federation/Céline Stucki



Picture 18.2 Sheet/ice dimensions. Photo courtesy of the ©World Curling Federation, from "The Rules of Curling," dated October 2015

Wheelchair

Wheelchairs are typically the person's own wheelchair. It can be a manual or power wheelchair and must have a footrest (see footnote 1). The wheelchair athlete's feet cannot touch the ground during play (see footnote 1). Typically, players cool their wheels prior to being on the ice by spending time near the backboards (see footnote 1). Wheelchair curlers can chose to have a post on the nondelivery arm side of their chair into order to hold onto it while curling for stabilization. Alternatively to a chair post, they could hold onto the nondelivery arm wheel (see footnote 1).

Rules and Regulations

Wheelchair curling is governed by the World Curling Federation (WCF). Wheelchair curling rules are very similar to able-bodied curling, with the exception of no sweeping is performed in wheelchair curling [1]. The following rules are adapted from the WCF "The Rules of Curling" dated October 2015 (see footnote 1). Please remember these rules are not meant to be all inconclusive and are subject to change per the WCF. All current rules are available for review via the World Curling website (see footnote 1).

General Rules

Competition in wheelchair curling consists of four players on a team and must include both females and males (see footnote 1). The players are the Skip (the Captain), the Lead, the Second, and the Vice. Players must maintain the delivery rotation. The Skip determines the weight (velocity), turn (the curl), or line (direction despite the curl) of the stone (see footnote 1). Each player delivers two stones per "end" (the way a curling game is divided, like innings in baseball), totaling eight stones per team. There are typically eight ends played in wheelchair curling (see footnote 1).

Once all 16 stones are played in an end, the goal is to have a stone of your team's closest to the center of the house. The team with the closest stone to the tee scores a point. They can score more points if they have two stones that are closest and so on. If a stone does not come to rest completely beyond the inside edge of the hog line, it is removed from play (unless it strikes another stone) (see footnote 1).

The Injured Player

If a player is unable to continue playing (the player can only leave the game once), then one of two situations can occur (see footnote 1). Either the three remaining players can continue to play until the player who left the game can return or a qualified alternative player can join at the beginning of an end (see footnote 1). The replaced player many not reenter if the latter is chosen (see footnote 1). If an alternative player is allowed in the competition, only one alternate player can be registered (see footnote 1).

If the situation occurs where a player plays one stone and cannot play the next, a teammate will finish the play (see footnote 1). If it is the first player or the third player that cannot finish the play, the second player delivers the stone. If it is the second player, the first player delivers (see footnote 1). If it is the fourth player, the third player delivers the stone. If a player is missing for any reason, the first two players deliver three stones each, and the third delivers two stones (see footnote 1). The missing player can later enter the game in the prior declared order or the players may use the alternate registered player (see footnote 1).

Wheelchair Setup (Picture 18.3)

Wheelchair users typically set their wheelchair in front of the house (see footnote 1). The stone must be released from the stick prior to reaching the hog line (see footnote 1). The chair must be positioned so that at the start of the delivery, the entire width of the stone is within the wheelchair lines (see footnote 1). When the delivery begins, the stone must be placed within 18 inches of the center line. Both of the athlete's

Picture 18.3 Curling action from the World Wheelchair Curling Championship 2016. ©World Curling Federation/ Céline Stucki

feet must be off the ice and on the footrest during delivery of the stone (see footnote 1).

Wheelchair Anchoring

Wheelchair curling requires the assistance of someone else to secure the chair and prevent it from rolling.[2] The athlete's wheelchair should be locked and in curling position as stated previously (Picture 18.3). A second wheelchair athlete can roll up behind the delivering athlete, lock their chair, and then lean forward to hold the competing athlete's wheelchair with both hands (see footnote 2). Likewise, a standing partner can put their foot behind the wheel on the side of the delivering arm while holding onto the delivering athlete's chair with both hands (see footnote 2).

Classification Process for Wheelchair Curling Athletes

Wheelchair curlers must have lower limb impairments to be eligible. Curlers that participate have multiple impairments including but not limited to spinal cord injuries, spina bifida, polyneuropathy, cerebral palsy, limb deficiency due to congenital malformation or amputations, or multiple sclerosis. In order for an athlete to compete in the World Wheelchair Curling Championship, World Wheelchair Curling Qualification events, and Paralympic Winter Games, they must undergo the WCF classification and eligibility process. The eligibility criteria are presented in Fig. 18.1 from the WCF Classification Rules, dated October 2014.[3] The athletes are either allocated to

[2]WCF: Discover Wheelchair Curling. [Internet] [cited 2016 March 9] [5 screens] http://www.worldcurling.org/discover-wheelchair-curling. Permission for use granted by the World Curling Federation

[3]WCF Classification Rules (V2-October 2014). [Internet] [cited 2016 March 9]. [Full PDF]. Available from: http://www.worldcurling.org/rules-and-regulations-downloads. Permission for use granted by the World Curling Federation

Fig. 18.1 Wheelchair curling athlete eligibility (see footnote 3)

The athlete must meet **one** of the following:

1. **Loss of power in the lower limbs** so that the total power in the legs is <40 points total. Movements tested are at the hips (flexion, extension, abduction, adduction), knees (flexion and extension), and ankles (plantar flexion and dorsi flexion). Power is rated according to the Oxford Scale [5] (*see appendix*). Grade 1 and 2 are counted as 0.
2. **Lower limb deficiency**: Examples, bilateral above the ankle, unilateral hip disarticulation, or unilateral above the knee amputation and muscle strength of the other leg less than 25/40 as per #1.
3. **Hypertonia**: Ashworth Scale [6] (*see appendix*) at grade 3 or 4 and sufficient to prevent all ambulation or limit it to very short distances. Can be used as separate eligibility criteria even if #1 is greater than 40. Examples: Cerebral Palsy.
4. **Incoordination in the lower limbs:** Loss of strength and hypotonia with objective ataxia so that ambulation is prevented or limited. Examples: Cerebral Palsy and Multiple Sclerosis.
5. **Restriction of Movement**: Permanent loss of joint range of motion of 50% or more of the large joints (hip, knee, ankle) in both legs. Examples: Arthrogryposis.
6. **Impairment Combination**: Any combination above that limits the athletes to a wheelchair for daily activity.

sports class eligible or non-eligible. Recall that these eligibility criteria are subject to change as determined by the WCF and are available for review via the World Curling website (see footnote 3).

Biomechanics

Wheelchair curling biomechanics involve understanding the upper body and the delivery arm (Picture 18.4). There is no use of the lower limbs in wheelchair curling, meaning the biomechanics to deliver the stone are very different from able-bodied curlers. The most important movement for the wheelchair curler is the forward motion of the delivery arm and the twist at the forearm and wrist that occurs to create the “curl” or rotation of the stone. In order to create a successful delivery, the grip on the delivery stick and stabilization of curler while curling are key. In wheelchair curling, the chair is static and therefore all of the momentum must come from the upper body to deliver the stone. In order create this momentum, the athlete must stabilize the nondelivery arm by holding onto the post or the wheel on the nondelivery side (see footnote 2). With regard to the grip on the stick, the grip should be in a “V” position (so that the index finger and thumb are as parallel as possible to the stick). Such a grip should allow for a very controlled and tactical delivery (see footnote 2).

Common Injuries and Injury Prevention

Common wheelchair athlete injuries are summarized in Fig. 18.2 and expanded in this section. For review of studies looking at injuries specific to wheelchair curlers, see Sect. “Wheelchair Curling Injuries” in this chapter.

Common Wheelchair Athlete Injuries

Upper Limb Injuries

In general for wheelchair sports, upper limb injuries are most commonly reported. A 1991 study reported injuries commonly occurred in the hand (20%), followed then by the shoulder (15.5%), fingers (11.1%), and arm (10%) [2]. Another study, looking at only wheelchair athletes in track and field, wheelchair basketball, quad rugby, fencing, table tennis, tennis, and volleyball, similarly demonstrated soft tissues injuries commonly occurring in the shoulder (18%), followed by the arm (12%) and the wrist (12%) [3]. The general consensus within the adaptive sport literature is that injuries

Picture 18.4 Curling action from the World Wheelchair Curling Championship 2016. ©World Curling Federation/Céline Stucki

Fig. 18.2 Common wheelchair sport injuries (For references, refer to text)

Upper Limb Injuries
Shoulder (15–72% of reported injuries)
–Largely muscle strains, tendinopathies, bursitis
Hand(~20%)/Fingers (~11%)/Arm (~10%)
–Tendinopathies, ligament strains, muscle strains, nerve entrapments (median mononeuropathy at the wrist and ulnar mononeuropathy at the elbow)

Soft Tissue Injuries
Commonly of limbs
–Blisters, lacerations, abrasions, pressure ulcers (~30% of reported injuries)

Spine Injuries
Possibly related to posture
–Muscle spasms, sprains

Lower Extremity Injuries
Less likely to have fractures or contusions without collision, but may occur related to impairments specific to each athlete

most commonly involve the shoulder, ranging between 15 [2] and 72% with the highest incidence in female wheelchair basketball players [4–6]. In those with arm injuries, the most likely diagnosis was muscle strains (52%), tendinopathy (30%), and bursitis (15.6%) and contusions [2, 3]. Interestingly, a 2012 Summer Paralympic study, which included all adaptive athletes (wheelchair and non-wheelchair users), determined that irrespective of impairment type, the upper limb accounted for 50.2% of all injuries, with the shoulder being most common (17.7%), followed by the wrist/hand (11.4%) and elbow (8.8%) [7, 8].

In wheelchair athletes, it appears chronic injuries (35–60%) may be more likely than acute, but this could be sport and study specific depending on the definition of acute versus chronic and methods to collect data [9–11]. Upper limb nerve entrapments are also common, specifically median mononeuropathy (50%) at the wrist and ulnar neuropathy (25%) at the wrist [12].

Spine Injuries

While the shoulder may be the most common site of reported pain in wheelchair athletes, the actual site of pathology in one study was determined to be the cervical and thoracic spine (59 and 8% respectively), suggesting common referral of pain to the shoulder [4]. This stresses the importance of a thorough physical examination.

Soft Tissue Injuries

Soft tissue injuries are often reported to include sprains, strains, and tendinopathies of the shoulder, elbow, arm, and hand, as well as blisters (74%), abrasions (68%), lacerations (12%), and decubitus ulcers (8.9%) [2]. Another study reported blisters and skin lacerations accounting for up to 35% of reported injuries [9]. Recall that the likely mechanism of blisters, abrasions, and lacerations (when there is not a collision involved) is contact of the hand or wrist with the chair rim. Since these may require minimum medical care, they may even be underreported [13].

Lower Extremity Injuries

The lower extremity incidence of injury is less common than the able-bodied population in wheelchair athletes [14]. Lower extremity fractures are more common in high speed adaptive sports with collision like wheelchair basketball, rugby, and softball [13].

Wheelchair Curling Injuries

Injuries specific to wheelchair curling athletes are available from the 2010 Winter Paralympic Games. In the 2010 survey of 50 curling athletes, 18% reported injuries. Injuries were from overuse or strain either to the upper limb (shoulder X 1, elbow X 1, wrist X 1) or spine (cervical X 3, thoracic X 1, lumbar X 2). However, less than half of the injuries were sport related. Overuse injuries are more likely than acute injuries [15], but injuries are still relatively uncommon in curling athletes compared to the other wheelchair sports. This is possibly because the sport does not involve repetitive overhead movements and wheelchair propulsion and utilizes minimal strength from the shoulder. Even though wheelchair curling is a low-risk sport, medical providers should be aware that serious injuries have occurred in other low-risk sports [15].

Able-Bodied Curling Injuries

When compared to wheelchair curling athletes, able-bodied curling injuries are similar in incidence and location. Four to twelve percentage of curling athletes sustained injuries in the 2010 Vancouver and 2014 Sochi Games [16, 17]. In 2010, overuse injuries were the most common [17], and this continued to be the trend in the 2014 Games where 75% of injuries reported were from overuse [16]. Injuries were reported most commonly in the low back, wrist, finger, and thigh, consisting of strains, tendinopathies, and muscle spasms [17]. While curlers seeking treatment for injuries may be low, 79% of curlers reported musculoskeletal pains, mainly in the knee, neck, and shoulder [18]. Less common injuries have been reported from falling on the ice (torn rotator, contusion, and shoulder strain) or from sweeping (herniated disk, “snapped” arm tendon, and back pain) [18]. When acute injuries do occur, over 90% of them were related to falls and 31.7% were head impacts (resulting in concussion, intracranial bleed, and soft tissue injury) [19].

Injury Prevention in Wheelchair Curling

Although there is no specific literature on injury prevention in wheelchair curlers, the most important function to preserve for performance is their delivery arm. Therefore, in order to prevent arm injuries and preserve sport performance (and daily function), a thorough physical exam should be performed to best determine if a rehabilitation program of the upper limb and cervical, thoracic, and lumbar spine is necessary. An evaluation of delivery arm technique should also be considered to prevent improper technique and overuse injuries.

All athletes should wear their seat belts to prevent falls on the ice. While falls from the wheelchair have not been reported in wheelchair curling athletes, they have been recorded in able-bodied curlers with significant trauma [19]. Given a wheelchair athlete with poor core strength, balance, and spasticity, a fall could certainly occur. A helmet should be considered for prevention of head trauma in such an athlete [19].

It is also helpful to review injury prevention strategies in general for wheelchair athletes.

Injury Prevention for Wheelchair Sports (General)

As stated previously, all athletes should undergo a thorough physical examination and a task-specific performance evaluation to help identify areas prone to excessive load. This could possibly help to diagnose and prevent sports injury mechanisms [20] [35].

In general, since wheelchair athletes are more likely to develop upper limb injuries, it is not unreasonable to address range of motion and strengthening of the upper body. This includes the upper back, shoulder, and scapular muscles in all wheelchair athletes [21, 22]. Injuries in the upper limb may be due to the repetitive use of the upper extremities for wheelchair propulsion and overhead activities (in both everyday life and sport). For example, repetitive wheelchair propulsion mechanics encourage repetitive protraction of the scapula, leading to altered posture, weaker scapular stabilizers, and tightening of anterior shoulder muscles [23]. This may place the upper limb at increased risk for microtrauma and subsequent overuse injuries, like rotator cuff tears [24]. It may also increase the risk for other arm injuries, like tendinopathies, while performing less common movements that are sport specific [25]. The "lack" of the entire kinetic chain during sports-specific tasks (like with racquet sports and throwing sports), and its role with regard to injuries, likely varies per wheelchair sport [26, 27].

The physician should also make sure that shoulder injuries are prevented "off the court." For example, there is already a higher incidence of rotator cuff tears in wheelchair users compared to non-wheelchair users, which may mean the wheelchair athlete is at even higher risk for rotator injuries [28, 29]. In order to prevent injuries "off the court," transfers and wheelchair propulsion should be monitored if applicable [30]. Physical therapy or occupational therapy should be considered for athletes who are at risk for injuries due to poor range of motion and improper technique seen with everyday functional tasks. This is especially important because the outcome of a sports-acquired injury would not only affect sports time but more importantly everyday functional tasks.

To expand on wheelchair ergonomics, assessment of the wheelchair in use may also help identify risk for nerve entrapments and spine injuries [31]. For example, nerve entrapments are likely secondary to hand rim mechanics causing repetitive trauma to the nerves at the wrist or elbow [12]. It would not be unreasonable to consider orthotics as needed to try and prevent such entrapments. The spine may also be at risk for injury due to atypical seating position in wheelchair athletes. For example, spinal cord athletes typically sit with a posterior pelvic tilt and increased kyphosis of the thoracic spine and demonstrate a head forward position [25]. This may place inappropriate stress on the spine and lead to microtrauma and degeneration within the spine. All wheelchair modifications that can be made, without violating chair guidelines within each sport, should be considered. It would also be reasonable to address core strength and spine strength in these athletes if possible.

Lastly, spinal cord athletes and cerebral palsy athletes have independent patterns of meeting energy demands during exercise (may not be anaerobic sources for power), and it is recommended that each strengthening program (such as intensity and frequency) be tailored toward the individual athlete's impairments [32].

Summary

Wheelchair curling is a sport that requires critical thinking, strategy, teamwork, and patience. Athletes are classified and eligible based on lower limb impairments. Curlers with spinal cord injury, amputation, and cerebral palsy are just some of the types of athletes who compete. It is one of few wheelchair sports where the athlete can use their everyday wheelchair and requires minimal additional equipment, making the cost to play affordable and appealing. The risk of injury is relatively small compared to other wheelchair sports, but the medical provider must be aware that serious injuries could still occur.

Appendix

Oxford Scale [33]

- 1: Flicker of movement
- 2: Through full range actively with gravity counterbalanced
- 3: Through full range actively against gravity
- 4: Through full range actively against some resistance
- 5: Through full range actively against strong resistance

Ashworth Scale [34]

- 0: No increase in tone
- 1: Slight increase in tone, catch when limb is moved
- 2: Marked increase in tone, limb easily flexed
- 3: Passive movement difficult
- 4: Limb rigid

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Wheelchair Tennis and Para-table Tennis

19

Mary Caldwell and Arthur Jason De Luigi

Wheelchair Tennis: Introduction

Wheelchair tennis originated in 1976, and it is now one of the largest growing adaptive sports globally, played in over 100 countries worldwide [1]. The popularity of wheelchair tennis, similar to able-bodied tennis, has led to a moderate amount of medical research. Such research has led to a better understanding of the sport-specific equipment, biomechanics, and injuries within wheelchair tennis players compared to that of other wheelchair sports [2–6]. The equipment, rules and regulations, athlete classification, biomechanics, and common injuries will be reviewed as pertinent to the wheelchair tennis player.

Rules and Regulations

Wheelchair tennis is governed by the International Tennis Federation (ITF). The 2016 ITF Wheelchair Tennis Regulations are summarized here [7]. The most notable difference from able-bodied tennis is that a double bounce is permitted for wheelchair users [7].

M. Caldwell, DO (✉)
Department of Rehabilitation Medicine,
MedStar National Rehabilitation Hospital,
MedStar Georgetown University School of Medicine,
Washington, DC, USA
e-mail: mary.elena.caldwell@gmail.com

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown
University School of Medicine,
Washington, DC, USA
e-mail: ajweege@yahoo.com

Court Setup

Tennis is played on a rectangular flat surface (Picture 1) [1]. A net is stretched across the center of the court, dividing it into two equal ends. Tennis can be played on glass, clay, or hard courts of concrete or asphalt topped with acrylic.

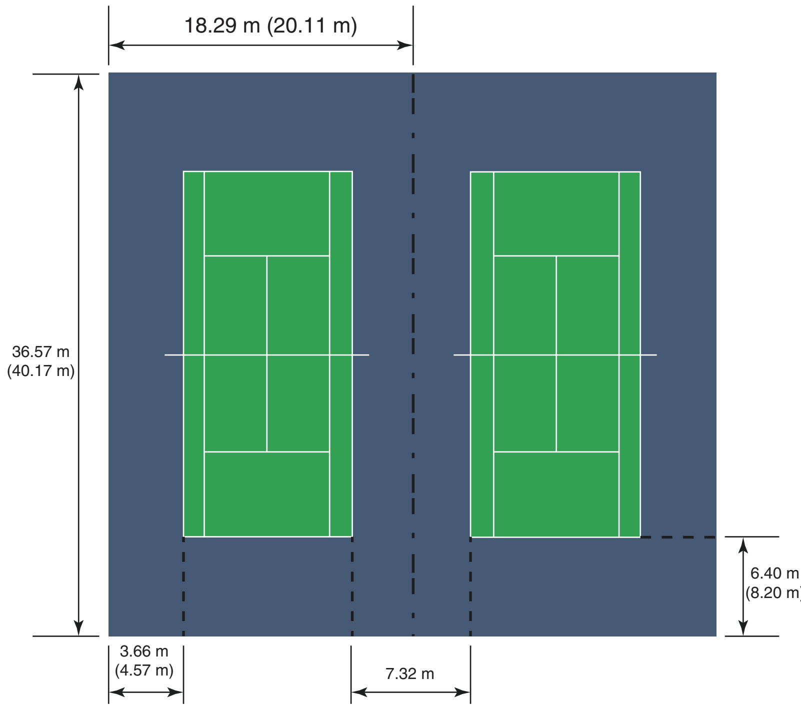
Lines on the court [1]:

- *Baselines*: Lines which delineate the width and edges of the court
- *Center mark*: Mark in the center of each baseline
- *Service line*: Line in the middle of the baseline and the net
- *Double sidelines*: Outermost lines that delineate the length, used in doubles games
- *Single sidelines*: Lines inside of the double lines, used in singles games
- *Center service line*: Line dividing the service line into two from the net to the service line, creating two boxes

Classification Process of Wheelchair Tennis Athletes

The following classification rules are adapted from ITF Wheelchair Tennis Classification Manual as of 2016, but because it is subject to

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_19



Picture 1 ITF recommended minimum dimensions for multiple tennis courts in international competitions. (Reproduced with permission from the ITF and available at http://www.itftennis.com/technical/facilities/facilities-guide/site-plan.aspx)

1. Hypertonia
2. Ataxia
3. Athetosis
4. Limb deficiency
5. Impaired passive range of motion
6. Impaired Muscle strength (determined by muscles used for running)
7. Leg length differences

*Subject to change yearly. Current minimal criteria based on 2016 Classification.

Fig. 19.1 Minimal disability criteria for wheelchair tennis [8]

yearly review and changes, a general overview is provided here [8]. Wheelchair tennis players should have a permanent impairment that alters the biomechanical execution of the running action to the point that it will adversely affect sport's performance. Further, such impairments must be assessed without aids or prosthetics [8].

Wheelchair tennis players can either be classified by the meeting minimal disability criteria (Fig. 19.1) or "quad" division criteria [8]. Athletes that participate in wheelchair tennis most commonly have a mobility related disability, including those with spinal cord injuries, strokes, brain injury, multiple sclerosis, spinal ataxia, cerebral palsy, amputations, limb deficiencies, or nerve injuries.

Quad Division Criteria

Athletes will be eligible for the quad division if they have a permanent impairment that alters their ability to manually use the wheelchair or to perform other sports-specific skills [8]. Again this is subject to yearly review [8]. Such skills include the overhead service, a continuous forehand, backhand, an inability to grip the racquet, and limited trunk function. Athletes also undergo "bench testing" which is available for review via the ITF. With bench testing, the strength and range of motion of the dominant limb and nondominant limb are classified according to the International Wheelchair Rugby Federation Classification Manual. Bench testing determines if the athlete meets impairment criteria for the quad division. If an athlete scores more than ten points out of the maximum 15 points, they are ineligible for the quad division [8].

Rules of Play

General Rules

Wheelchair tennis can be played as singles or between two teams of two players each (doubles) [7]. The general object of the game is to play the ball across the court so that the opposing player cannot make a valid return. The player that does not return the ball will not gain a point, whereas the opposite player will. Players are on opposite sides of the net. One player is the server; the opposite player is the receiver. If a wheelchair tennis player is playing with or against an able-bodied person in singles or doubles, the rules of wheelchair tennis apply to the wheelchair athlete, while the rules of tennis apply to the able-bodied athlete [7].

Serves

For each serve, the server starts behind the baseline, between the center mark and the sideline. Immediately before the serve, the wheelchair server is in a stationary position and is allowed only one push before serving [7]. If a conventional serve (kick serves and flat serves) is not possible for a wheelchair player (like a quad player), then the player or another individual may drop the ball for that player and allow it to bounce before being struck. The same strategy must be used throughout the match.

The player can also kick the ball up to be served. The ball must travel over the net, without touching the net, into the diagonal and opposite service box. If the ball hits the net, but lands in the service box, it is a "let" (which is considered void) and the server serves again [7]. If the wheelchair player's wheel touches the baseline or the foot of an able-bodied server touches the baseline before the ball is hit, this is a "fault." Two consecutive faults, is called a double fault, and the other player gets a point [7].

Plays

Once a rally starts, the player or team cannot hit the ball twice in a row. The "two-bounce rule" for wheelchair tennis players is as follows: the wheelchair player is allowed two bounces of the ball and the second bounce can either be in or out of the court boundaries [7]. The wheelchair player loses points if they fail to return the ball before it bounces three times or if the player uses any part of their feet. The wheelchair player must keep one buttock in contact with the chair when contacting the ball. If the player cannot propel the chair with the wheel, then they may use a foot; if they use a foot, the foot cannot be in contact with the ground during the forward motion of a swing through contact with the ball [7].

Scoring: Game, Set, Match

A game is won by the player who has four points in total or at least two points above the opponent. Scores of zero, one, two, and three are read as "love, fifteen, thirty, and forty," and if both players are at forty each, it is read as "deuce." The game advances until a player has won by two points [7].

A set consists of multiple games between the two players and lasts until a player wins at least six games with at least two games more than the opponent. The exception to the latter occurs if the set is tie at six games apiece, then a game occurs where the players alternate serves until someone leads by two points, and the final of the set would then be scored 7–6 [7].

A set break occurs at the conclusion of each set; there is a 2 min break until the time the first serve is struck for the next set. A match is complete after a sequence of three or five sets, depending on the events [7].

Important Medical Rules

A physician should be present at the event to evaluate and assess any injuries or illnesses that occur [7]. Although it is not mandatory, it is beneficial and preferable to the physician who has knowledge of spinal cord injuries and other disabilities. However, it is the goal of this chapter to provide fundamental knowledge for any volunteering physician to be comfortable with common conditions and injuries that one may encounter while covering wheelchair tennis.

Tournaments will provide shade and ice buckets on court for players with quadriplegia to prevent heat injuries given these athletes difficulties with thermoregulation. There are two toilet breaks permitted during a match. These are typically taken at a set break, which can be very important for spinal cord athletes to prevent autonomic dysreflexia due to an overdistended bladder or withholding a bowel movement [7].

An athlete can request a medical evaluation during a set break. Otherwise, only an acute medical condition can stop the play. An athlete is limited to two changeovers/set breaks for each treatable medical condition. If the player has a treatable condition, the medical team can determine if the player should continue [7]. A "medical time-out" is called if additional time for medical treatment is required. A time-out can only be 3 min long. Only one medical time-out is allowed per player and for each treatable medical condition. For example, all clinical manifestations of heat illness are considered one condition as are all treatable musculoskeletal injuries that manifest as part of the kinetic chain [7].

There are specific guidelines for certain conditions. For example, muscle cramping can only be treated during the change of ends/set breaks, unless it is part of one overall condition (like heat illness). If bleeding occurs, play should be stopped immediately and the medical team has up to 5 min to control the bleeding [7].

Equipment

Wheelchair

The wheelchair can be a sports wheelchair or an everyday wheelchair. Tennis players that meet bench test requirements can use a power wheelchair. The sports wheelchair often has a footrest, rear anti-tip tubes, a front caster, and a back caster [7]. They typically have non-marking tires that do not damage the court surface. Most tennis wheelchairs have wheels with a camber up to 25°, which provides a stable base for the player to move around the court [1]. Tennis wheelchairs also can have handles on the front seat for the athlete to stabilize themselves during a play [9]. Of note, there must be a secure place for players to store their tennis wheelchairs overnight at the events.

Racquet and Ball

Racquets must be approved by the ITF [1]. Tennis players with quadriplegia are allowed to use extra-long racquets in case where tape is required to secure the racquet to the player's arm or hand. A player with quadriplegia can be given extra time to reposition or adjust the racquet without penalty during a match [7]. The balls used in matches vary depending on court type or even altitude of play but must be approved by the ITF [1].

Biomechanics

The tennis serve consists of four phases as described in Table 19.1 [10]. Shoulder joint biomechanics and kinetics of the wheelchair tennis serve has been studied and reviewed by Reid et al. [10] compared to able-bodied tennis players, and therefore this will be the focus of this section.

In the study by Reid, wheelchair tennis players rotated their upper arms to positions of maximal external rotation 20° less than that seen in the able-bodied serve [10]. During forward swing, wheelchair tennis players have less trunk flexion, similar amounts of lateral trunk flexion, and more variable trunk rotation

Table 19.1 The tennis serve

1. Cocking (the racquet's highest point of vertical displacement in the backswing to maximal external rotation)
2. Swing (from the racquet's highest point to the time right before ball impact)
3. Forward swing (from maximal external rotation to racquet-ball impact)
4. Follow-through (brief time period post impact)

[10]. The humeral internal rotation during forward swing was 40–80% lower than that of able-bodied players [10]. Wheelchair tennis players have similar absolute pre-impact racquet velocities versus able-bodied players [10]. When compared to the able-bodied tennis serve, there was an estimated 33% reduction in the maximum pre-impact absolute and horizontal racquet velocities [10]. Further, relative post-impact peak external rotation moments and mean compressive forces (in the follow-through phase) were higher in able-bodied tennis serves compared to wheelchair tennis serves. In other words, wheelchair athletes did not demonstrate the expected compensatory kinetic response, like that seen in other adaptive athletes [10, 11].

There are important implications for these biomechanical differences observed in wheelchair tennis players. It appears the lack of the kinetic chain may work to the advantage of the wheelchair tennis player, unlike other sports where it may lead to increased forces throughout the shoulder [12]. For example, the mean plane of arm elevation in wheelchair tennis players was less than 180°, meaning their arms remained anterior to their shoulder alignments and suggesting less risk for impingement syndromes [10]. Further, wheelchair tennis players had a higher arm-thorax elevation angle during serves compared to able-bodied athletes [10]. This may actually help take load off the shoulder joint and improve speed. Reid's study suggests that higher shoulder joint loading conditions may not occur in wheelchair tennis players, and therefore shoulder injuries are no more likely in wheelchair tennis players over able-bodied tennis players [10].

Common Injuries and Injury Prevention

Common wheelchair athlete injuries are summarized in Fig. 19.2 and expanded in this section. For review of studies looking at injuries specific to wheelchair tennis athletes, see Sect. "Wheelchair Tennis Injuries" in this chapter.

Common Wheelchair Athlete Injuries

Upper Limb Injuries

In general for wheelchair sports, upper limb injuries are most commonly reported. A 1991 study reported injuries commonly occurred in the hand (20%), followed then by the shoulder (15.5%), fingers (11.1%), and arm (10%) [13]. Another study, looking at only wheelchair athletes in track and field, wheelchair basketball, quad rugby, fencing, table tennis, tennis, and volleyball, similarly demonstrated soft tissue injuries commonly occurring in the shoulder (18%), followed by the arm (12%) and the wrist (12%) [14]. The general consensus within the adaptive sport literature is that injuries most commonly involve the shoulder, ranging between 15 [13] and 72% with the highest incidence in female wheelchair basketball players

Upper Limb Injuries
Shoulder (15-72% of reported injuries)
-Largely muscle strains, tendinopathies, bursitis
Hand (~20%)/Fingers (~11%)/Arm (~10%)
-Tendinopathies, ligament strains, muscle strains, nerve entrapments (median mononeuropathy at the wrist and ulnar mononeuropathy at the elbow)
Soft Tissue Injuries
Commonly of limbs
-Blisters, lacerations, abrasions, pressure ulcers (~30% of reported injuries)
Spine Injuries
Possibly related to posture
-Muscle spasms, sprains
Lower Extremity Injuries
Less likely to have fractures or contusions without collision, but may occur related to impairments specific to each athlete

Fig. 19.2 Common wheelchair sport injuries (For references, refer to text.)

[15–17]. In those with arm injuries, the most likely diagnosis was muscle strains (52%), tendinopathy (30%), and bursitis (15.6%) and contusions [13, 14]. Interestingly, a 2012 Summer Paralympic study, which included all adaptive athletes (wheelchair and non-wheelchair users), determined that, irrespective of impairment type, the upper limb accounted for 50.2% of all injuries, with the shoulder being the most common (17.7%), followed by the wrist/hand (11.4%) and elbow (8.8%) [18, 19].

In wheelchair athletes, it appears chronic injuries (35–60%) may be more likely than acute, but this could be sport and study specific depending on the definition of acute versus chronic and methods to collect data [20–22]. Upper limb nerve entrapments are also common, specifically median mononeuropathy (50%) at the wrist and ulnar neuropathy (25%) at the wrist [23].

Spine Injuries

While the shoulder may be the most common site of reported pain in wheelchair athletes, the actual site of pathology in one study was determined to be the cervical and thoracic spine (59% and 8% respectively), suggesting common referral of pain to the shoulder [15]. This stresses the importance of a thorough physical examination.

Soft Tissue Injuries

Soft tissue injuries are often reported to include sprains, strains, and tendinopathies of the shoulder, elbow, arm, and hand, as well as blisters (74%), abrasions (68%), lacerations (12%), and decubitus ulcers (8.9%) [13]. Another study reported blisters and skin lacerations accounting for up to 35% of reported injuries [20]. Recall that the likely mechanism of blisters, abrasions, and lacerations (when there is not a collision involved) is contact of the hand or wrist with the chair rim. Since these may require minimum medical care, they may even be underreported [24].

Lower Extremity Injuries

The lower extremity incidence of injury is less common than the able-bodied population in wheelchair athletes [25]. Lower extremity fractures are more common in high speed adaptive sports with collision like wheelchair basketball, rugby, and softball [24].

Wheelchair Tennis Injuries

The incidence rate of wheelchair tennis injuries was reported as ~12.8 per 1000 athlete days at the 2012 Summer Paralympics, with the overall injury incidence rate being 12.7 [18]. Wheelchair tennis athletes reported 19 injuries (out of 106 athletes), 37% were acute injuries and 47% were overuse injuries. This is compared to boccia (91% acute (10× the amount of chronic injuries)) and goalball (77% acute (7× the amount of chronic injuries)) [18]. Wheelchair tennis is considered overall a low risk for injury when compared to high-risk sports like cycling, basketball, and rugby [26], but it still has a higher injury risk compared to bowling, billiards, table tennis, archery, and field events [20]. In a 1992 Paralympic study, 75% of wheelchair tennis players acquired an injury during training or competition [27].

With regard to the common risk for soft tissue injuries in wheelchair sports (strains, sprains, tendinopathy, bursitis) [14], certain soft tissues injuries may be more commonly seen in wheelchair tennis players, such as “tennis elbow” [10].

Shoulder injuries commonly seen in wheelchair tennis players are available by Jeon et al. [28]. Jeon performed ultrasonographic evaluation of the shoulder of 33 elite wheelchair tennis athletes and determined that the most common pathology in the dominant shoulder was acromioclavicular pathology (63.6%). Supraspinatus tears were found in eight dominant shoulders and six nondominant shoulders. The study found no correlation to shoulder pathology and the different variables studied including age, training time, or length of career/wheelchair use [28]. This study was limited by the fact that the pathologies seen may be related to the sport or everyday wheelchair use.

Another study compared scapular resting position and shoulder pain among wheelchair basketball players, amputee soccer players, and wheelchair tennis players. The study assessed scapular dyskinesis, as described by Kibler [29], and found that 54.5% had abnormal resting scapular positions (as well as more pain) compared to the non-wheelchair athletes (15.8%), suggesting frequent use of the wheelchair was responsible for the scapular dyskinesis. Racquet sport wheelchair players may therefore be prone to shoulder injuries since the movements performed during sport performance are different than those used in everyday wheelchair propulsion [30].

It is also important to remember that besides musculoskeletal injuries, illnesses can occur. For example, wheelchair tennis athletes, particularly ones with spinal cord injuries, are at higher risk of impaired thermoregulatory function and heat illnesses compared to wheelchair tennis players without spinal cord injury. The physician must be prepared to implement treatment [31].

Able-Bodied Tennis Injuries

There is a large body of literature reviewing the epidemiology of musculoskeletal injury in a tennis player, and it will only be briefly reviewed here in order to allow for comparison to wheelchair tennis injuries. According to a literature review in 2012 by Abrams et al., most able-bodied tennis injuries occur in the lower extremity (31–67%), followed closely by the upper extremity (20–49%) and trunk (3–21%) [32]. The authors also noted that chronic injuries were more common in the arm, while acute injuries were more common in the leg [32, 33]. The ankle and thigh (specifically ankle sprains) and the elbow and shoulder (specifically lateral epicondylitis) were the most commonly reported site of injuries for the lower limb and upper limb, respectively [32, 34]. Lateral epicondylitis was also the most common overuse injury [34]. With regard to the shoulder, younger tennis players tended to have shoulder pain secondary to shoulder instability, while older tennis players were more likely to have rotator cuff pathology [35]. Other common injuries (besides rotator cuff and lateral epicondylitis) for racquet sports in general are overdevelopment of the dominant arm, forearm nerve entrapments, low back pain, abdominal wall sprain, and tennis leg and eye injuries [36].

Injury Prevention in Wheelchair Tennis Players

Injury preventions have been proposed for wheelchair tennis athletes. Croft et al. proposed that with regard to the physiological demands of wheelchair tennis, wheelchair tennis players should have training through a full exercise intensity spectrum compared to other wheelchair athletes in order to compete safely. Of note, wheelchair tennis players with spinal cord injuries have been able to reach such physiologic thresholds for exercise intensity similar to able-bodied tennis players [37]. However, a study determined that physiologic parameters (such as peak oxygen uptake) do not correlate to wheelchair tennis ranks (i.e., performance), making it unclear the role physiologic-based training has in performance and injury prevention [38].

Wheelchair ergonomics must also be assessed including seat positioning, rear-wheel camber, wheel size, and hand-rim configurations [39]. A small survey revealed that wheelchair tennis athletes agreed that stability was the most important wheelchair contributor to performance, while camber was reported to have both positive and negative effects [40]. For more information on wheelchair ergonomics, see general injury prevention section.

There have been several risk factors identified with regard to injury in able-bodied tennis players that have yet to be assessed in wheelchair tennis players. For example, volume of play has been associated [33] with overall increased injury rate, while racquet grip and skill level may be risk factors for specific injuries [32]. Specifically for lateral epicondylitis (more common referred to as lateral epicondylitis), studies have looked at the two-handed versus one-handed backhand [41], vibration dampeners [34], and racquet grip size [32, 42], but there is inconclusive evidence on what role they may play in developing the pathology. It is likely that the etiology is secondary to improper technique [43] and time spent playing each week [44]. Risk factors that should be addressed to prevent recurrent shoulder injury in able-bodied tennis players have been identified as glenohumeral internal rotation deficit, rotator cuff strength (particularly the external rotators), and scapular dyskinesis [45, 46].

Injury Prevention for Wheelchair Sports (General)

As stated previously, all athletes should undergo a thorough physical examination and a task-specific performance evaluation to help identify areas prone to excessive load [36].

In general, since wheelchair athletes are more likely to develop upper limb injuries, it is not unreasonable to address range of motion and strengthening of the upper body. This includes the upper back, shoulder, and scapular muscles in all wheelchair athletes [47, 48]. Injuries in the upper limb may be due to the repetitive use of the upper extremities for wheelchair propulsion and overhead activities (in both everyday life and sport). For example, repetitive wheelchair propulsion mechanics encourage repetitive protraction of the scapula, leading to altered posture, and tightening of anterior shoulder muscles [49]. This may place the upper limb at increased risk for microtrauma and subsequent overuse injuries, like rotator cuff tears [50] and tendinopathies [30]. The "lack" of the entire kinetic chain during sports-specific tasks (like with racquet sports and throwing sports), and its role with regard to injuries, likely varies per wheelchair sport [10, 12].

The physician should also make sure that shoulder injuries are prevented "off the court." For example, there is already a higher incidence of rotator cuff tears in wheelchair users compared to non-wheelchair users, which may mean the wheelchair athlete is at even higher risk for rotator injuries [51, 52]. In order to prevent injuries "off the court," transfers and wheelchair propulsion should be monitored if applicable [53]. Physical therapy or occupational therapy should be considered for athletes who are at risk for injuries due to poor range of motion and improper technique seen with everyday functional tasks.

To expand on wheelchair ergonomics, assessment of the wheelchair in use may also help identify risk for nerve entrapments and spine injuries [39]. For example, nerve entrapments are likely secondary to hand-rim mechanics causing repetitive trauma to the nerves at the wrist or elbow [23]. It would not be unreasonable to consider orthotics as needed to try and prevent such entrapments. The spine may also be at risk for injury due to atypical seating position in wheelchair athletes. For example, spinal cord athletes typically sit with a posterior pelvic tilt and increased kyphosis of the thoracic spine and demonstrate a head forward position [30]. This may place inappropriate stress on the spine and lead to microtrauma and degeneration within the spine. All wheelchair modifications that can be made, without violating chair guidelines within each sport, should be considered.

Lastly, spinal cord athletes and cerebral palsy athletes have independent patterns of meeting energy demands during exercise (may not be anaerobic sources for power), and it is recommended that each strengthening program (such as intensity and frequency) be tailored toward the individual athlete's impairments [54].

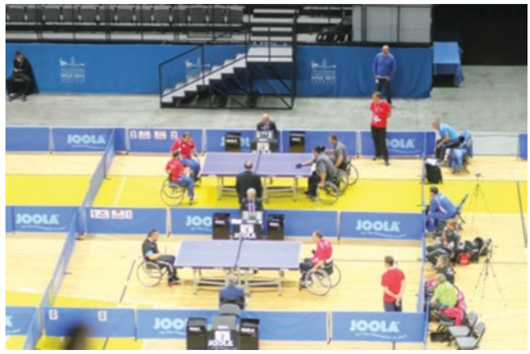
Summary

Wheelchair tennis athletes must have an impairment that alters the biomechanics of running. They may have spinal cord injuries, strokes, brain injuries, multiple sclerosis, spinal ataxia, cerebral palsy, amputations, limb deficiencies, or nerve injuries. The sport is very similar to able-bodied tennis, with the exception a two-bounce rule for wheelchair athletes. There are two main athlete classifications, the minimal disability division criteria and the quad division criteria. Wheelchair tennis players are generally at low risk for injury compared to other wheelchair sports, with overuse injuries being the most common. However, the medical team should be prepared to treat impairment-related illnesses, such as heat illnesses. Wheelchair tennis player shoulder kinetics do not demonstrate a compensatory kinetic response like that seen in other athletes. Further, the wheelchair tennis player's adaptive serve may actually make their risk of injury no more likely than that of able-bodied tennis players.

Para-table Tennis: Introduction

Table tennis for differently abled athletes involves both standing athletes and wheelchair athletes with disabilities (Pictures 2 and 4), and it is therefore commonly referred to as para-table tennis (PTT) and not wheelchair table tennis [55].

Picture 2 Gwangju World Championships. Photo courtesy © Gaël Marziou, Para Table Tennis Webmaster. Reproduced with permission



Picture 3 Para-table tennis court setup. Picture taken at 2011 European Championships, photo courtesy © Gaël Marziou, Para Table Tennis Webmaster. Reproduced with permission

Picture 4 2010 French Open. Photo features Peter Rosenmeier of Denmark. Photo courtesy © Gaël Marziou, Para Table Tennis Webmaster. Reproduced with permission

The sport was first included in the Summer Paralympic Games in 1960 and is very popular as it allows for athletes with all physical impairments to compete (except for the visually impaired), including those with intellectual impairments [55]. The equipment, rules and regulations, athlete classification, biomechanics, and common injuries will be reviewed as pertinent to the PTT player.

Rules and Regulations

The rules and regulations of PTT are governed by the International Table Tennis Federation (ITTF) [56]. In order to compete in PTT, athletes must have a permanent impairment that affects their sports performance making them unable to participate in able-bodied table tennis.

Court Setup

The table must be rectangular and is typically 2.74 m long and 1.525 m wide. The table can be set up on any approved ground surface, including concrete [56]. Table legs should be at least 40 cm from the end line of the table for wheelchair players (Picture 3). Any table surface is valid as long as the ball bounces 23 cm off the surface when dropped from a height of 30 cm. A white sideline and white end line, 2 cm wide, must line the table [56]. The table is then divided into two equal courts by a vertical net. For doubles, each court is then divided into half courts by a line running parallel with the sidelines [56].

Classification of Para-table Tennis Players

PTT players truly are a mix of all different impairments, ranging from spinal cord injury, stroke, and cerebral palsy to all different types and levels of amputations. Particularly important to PTT is that it includes those with intellectual impairments, different from many other adaptive sports [55]. When the PTT undergoes classification to compete, they must wear all their gear (including orthotics/prosthetics) and the wheelchair (if using one) that they would use during competition [57]. In order to be assigned a sports class, they undergo a physical assessment, technical assessment, and observational assessment. Following this, the player is assigned a sports class (classes 1–11) and a sports class status (new, review, or permanent) [57]. Classes 1–5 compete in a wheelchair, classes 6–10 compete standing, and class 11 is for players who have intellectual impairments as well [57]. The classes are available for review as in Fig. 19.3 [57].

Minimal disability for sitting classes (highest being class 5) is determined as such [57]:

- Not able to stand or walk without two crutches.
- Not able to step sideways.
- Hyperlordotic and hip posterior tilt without crutches.
- When sitting, the athlete cannot bend full to the side at normal speed and raise again at normal speed.
- There is reduction of speed in forward/backward movement.
- Neurological level of spinal cord lesion is S1–2.
- All athletes with polio should be comparable to impairments above.

Minimal disability for standing classes (highest being class 10) is determined as such [57]:

- Only very minimal impairments in one extremity (upper, lower, or spine).
- If in the back, the impairment affects rotation.

Class 1: No sitting balance and function severely affected in playing arm.
- Weak grip, weak wrist flexors, no elbow extension, neck and shoulder function are normal
- *Examples: Spinal cord injury at C5 or higher, cerebral palsy*

Class 2: No sitting balance but their playing arm is less affected than class 1.
- No normal strength of the hand, elbow extension functional.
- *Examples: Spinal Cord lesion C5 through C7, cerebral palsy.*

Class 3: No sitting balance (upper part of the trunk may show activity) and normal arms with minor motor losses in the hands.
- *Examples: Spinal cord injury C8-T9, cerebral palsy.*

Class 4: Sitting balance is suboptimal and fully functional arms and hands.
- *Examples: Spinal cord lesion T8-L2, cerebral palsy.*

Class 5: Normal sitting balance, normal arm and hand function.
- *Examples: Spinal cord lesion L1-S2.*

Class 6: Severe impairments in arms and legs
- *Examples: Due to incomplete spinal cord injury, cerebral palsy with diplegia or athetosis, amputations in playing arm and leg, congenital conditions such as muscular dystrophy, players that handle the racquet with their mouth.*

Class 7: Very severe impairments of the legs or severe to moderate impairments of the playing arm or combination of arms and legs impairments, but less severe than class 6.
- *Examples: Single above elbow amputation, above knee and below knee am putations, incomplete spinal cord injury, moderate cerebral palsy with hemiplegia or diplegia.*

Class 8: Moderate impairment of the legs or a moderately affected playing arm
- *Examples: One non-functional leg, incomplete spinal cord injury, single below elbow amputation with long stump more than 1/3 but without functional wrist joint.*

Class 9: Mild impairment that affects the legs or the playing arm or can have severe impairments of the non-playing arm.
- Examples: Polio of the legs, single limb below knee amputation, stiff hip, amputation through the hand without functional grip, amputation through the non playing shoulder, mild Cerebral palsy with hemiparesis of non playing arm.

Class 10: Minimal impairment of leg or playing arm or non-playing arm or moderate impairment of the trunk
- Examples: Single stiff ankle, amputation of forefoot, finger amputation, extreme kyphosis, or back fusion.

Class 11: Intellectual impairment who also meet criteria for PTT.

For more information on classes please refer to http://www.ipttc.org/classification/ITTF-Classification-Code-final-March-2010.pdf or the most updated PDF from ITTF [57]

Fig. 19.3 Classification of para-table tennis players [57]

- If in the leg, the impairment affects balance and displacement and rotation of the hips.
- If in the upper extremity, the impairment can be mild in the playing arm (affects reach, speed of swing, and strength of the grip) or moderate to severe in the nonplaying arm (affects compensatory motions).

Rules of Play

General Overview of Terms [56]

- The *server* strikes first in a rally.
- The *receiver* strikes second in a rally.
- A *rally* is the period the ball is in play.
- A *let* is a rally, which is not scored.
- A *point* is a rally of which the result is scored.
- A player *strikes* the ball if it is touched with the racquet or if it is struck with the racquet hand below the wrist.
- A player *obstructs* the ball if anything they are wearing or carrying touches it in play or if they were to touch it before it strikes their court since being hit by the opponent.

General Rules

- The serve starts with the ball resting freely on the server's stationary free hand.
- The server then vertically throws the ball up, without any spin, so that it rises 16 cm after leaving the palm and then falls before being struck [56].
- The ball should be hit so that it bounces in the server's court first and then the receiver's court. In doubles, the ball must touch the right half court of both the server and receiver [56].
- The ball shall be returned so that it touches the opponent's court either directly or after touching the net assembly [56].
- In doubles involving wheelchair players, any player of the team can make a return (i.e., they do not have to alternate returns). However, in order to make a return, neither the standing player nor the wheelchair player's wheelchair can cross the center line of the table, or the other team gets a point [56].
- A rally shall be a let if the receiver is not ready to receive, if the ball touches the net, if the ball comes to a rest after touching the receiver's court, if the ball leaves the receivers court after touching the sidelines (in singles), or if the ball returns in the direction of the server after touching the receiver's court [56].
- A game is won by the player or pair first scoring 11 points, or if both sides have ten points, the game must be won by a lead of two points [56].
- A match is the best of any odd number of games. For example, in the 2016 Paralympic Games, it is the best of three matches, with each match being best of five games [58].
- Singles compete in classes 1 through 10 [58] and there are ways of combining classes if not enough players per group [58].
- Teams can be made up of two, three, or four players and mixed class teams are allowed, but the team must play in the class of the player with the highest class [58].

Points

A point is scored for many reasons: if an opponent makes an incorrect service or fails to make a correct return, if the ball touches anything other than the net assembly prior to being struck by the opponent, or if the ball passes over the receiver's court after being stuck by an opponent [56].

Wheelchair users must be aware that a point can be scored if the opponent's hand(s) touch the playing surface before striking the ball or if the opponent's footrest or foot touches the floor during play [56]. A point is also scored if the opponent does not maintain contact with the seat or cushion with the back of the thigh when the ball is struck. Once two points are scored, the receiver shall become the server [56].

Equipment

Ball and Racquet

The ball should have a diameter of 40 mm and weigh 2.7 g. All balls should be made of celluloid or similar plastics and be of regulation color

[56] (Picture 4). The racquet can be any size, shape, or weight. The blade must be flat or rigid and at least 85% of its thickness made of natural wood [56]. The striking side of the blade is covered with rubber that can either be ordinary pimpled rubber or sandwich rubber as per the guidelines. The player must show both their opponent and the umpire their racquet at the start of a match or whenever the racquet is changed [56].

Wheelchair

Wheelchairs (Picture 5) should have at least two large wheels and one small wheel [58]. While using the chair, no part of the player's body (above the knees) can be attached to the chair [58]. There are exceptions for medical reasons, and in such cases, it will be included on their international classification card. For example, the player must have the permission to wear a belt around their waist or corset and how often/long they will wear the belt is approved as per their doctor [58]. If the player has a seat cushion, the height is limited to 15 cm total (for maximum of two cushions) [58]. Since the wheelchair is included in the player's classification process, any and all changes to the wheelchair will require reclassification [58].

Picture 5 Photo features Maxime Thomas of France after winning the match for bronze medal at the open. Photo courtesy © Gaël Marziou, Para Table Tennis Webmaster. Reproduced with permission

Biomechanics

PTT players use alternative biomechanics compared to their able-bodied counterparts (Picture 6). There are no direct studies of PTT player kinetics versus able-bodied table tennis player kinetics. Given the lack of literature on the kinetics of PTT, able-bodied table tennis players will be discussed and the data extrapolated in order to determine possible similarities and differences in the adaptive player.

In the able-bodied player, the upper limb, trunk, and lower limbs all play in role in sports performance. The shoulder undergoes short, abrupt, and rapid movements often without having a swingphase [36]. The wrist undergoes a frequent combination of extension, flexion, supination, and pronation to impart spin during serves [36]. The trunk must have

Picture 6 Rolf Erik Paulsen of Norway. Photo courtesy © Gaël Marziou, Para Table Tennis Webmaster. Reproduced with permission

strength and good range of motion as both are crucial to the transference of force throughout the kinetic chain [36]. The lower limb undergoes fast lateral movements making the integrity of the hip, knee, and ankle crucial for success [36].

In the PTT player, given the multiple classifications and impairments, it is likely each player will adapt in their own and have different biomechanics from the able-bodied players. It may be that in players with trunk weakness or trunk decreased range of motion, the athletes would compensate with their upper limbs and put more force through their shoulder, elbow, or wrist [10]. One strategy an adaptive player could implement to limit trunk involvement would be to play at a high ball frequency, which limited trunk axial motion in able-bodied table tennis players [59]. Due to the wide range of impairments seen in PTT, each player should be observed participating in the sport to best assess their adapted biomechanics and to intervene (if needed) in order to prevent injuries.

Common Injuries and Injury Prevention

Common wheelchair athlete injuries are summarized in Fig. 19.4 and expanded in this section. For review of studies looking at injuries specific to wheelchair PTT athletes, see Sect. "Para-table Tennis Injuries" in this chapter.

Common Wheelchair Athlete Injuries

Upper Limb Injuries

In general for wheelchair sports, upper limb injuries are most commonly reported. A 1991 study reported injuries commonly occurred in the hand (20%), followed then by the shoulder (15.5%), fingers (11.1%), and arm (10%) [13]. Another study, looking at only wheelchair athletes in track and field, wheelchair basketball, quad rugby, fencing, table tennis, tennis, and volleyball, similarly demonstrated soft tissue injuries commonly occurring in the shoulder (18%), followed by the arm (12%) and the wrist (12%) [14]. The general consensus within the adaptive sport literature is that injuries most commonly involve the shoulder, ranging between 15 [13] and 72% with the highest incidence in female wheelchair basketball players [15–17]. In those with arm injuries, the most likely diagnosis was muscle strains (52%), tendinopathy (30%), and bursitis (15.6%) and contusions [13, 14]. Interestingly, a 2012 Summer Paralympic study, which included all adaptive athletes (wheelchair and non-wheelchair users), determined that irrespective of impairment type, the upper limb accounted for 50.2% of all injuries, with the shoulder being the most common (17.7%), followed by the wrist/hand (11.4%) and elbow (8.8%) [18, 19].

In wheelchair athletes, it appears chronic injuries (35–60%) may be more likely than acute, but this could be sport and study specific depending on the definition of acute versus chronic and methods to collect data [20–22]. Upper limb

Upper Limb Injuries
Shoulder (15-72% of reported injuries)
-Largely muscle strains, tendinopathies, bursitis
Hand (~20%)/Fingers (~11%)/Arm (~10%)
-Tendinopathies, ligament strains, muscle strains, nerve entrapments (median mononeuropathy at the wrist and ulnar mononeuropathy at the elbow)
Soft Tissue Injuries
Commonly of limbs
-Blisters, lacerations, abrasions, pressure ulcers (~30% of reported injuries)
Spine Injuries
Possibly related to posture
-Muscle spasms, sprains
Lower Extremity Injuries
Less likely to have fractures or contusions without collision, but may occur related to impairments specific to each athlete

Fig. 19.4 Common wheelchair sport injuries (For references, refer to text) nerve entrapments are also common, specifically median mononeuropathy (50%) at the wrist and ulnar neuropathy (25%) at the wrist [23].

Spine Injuries

While the shoulder may be the most common site of reported pain in wheelchair athletes, the actual site of pathology in one study was determined to be the cervical and thoracic spine (59% and 8%, respectively), suggesting common referral of pain to the shoulder [15]. This stresses the importance of a thorough physical examination.

Soft Tissue Injuries

Soft tissue injuries are often reported to include sprains, strains, and tendinopathies of the shoulder, elbow, arm, and hand, as well as blisters (74%), abrasions (68%), lacerations (12%), and decubitus ulcers (8.9%) [13]. Another study reported blisters and skin lacerations accounting for up to 35% of reported injuries [20]. Recall that the likely mechanism of blisters, abrasions, and lacerations (when there is not a collision involved) is contact of the hand or wrist with the chair rim. Since these may require minimum medical care, they may even be underreported [24].

Lower Extremity Injuries

The lower extremity incidence of injury is less common than the able-bodied population in wheelchair athletes [25]. Lower extremity fractures are more common in high speed adaptive sports with collision like wheelchair basketball, rugby, and softball [24].

Para-table Tennis Injuries

The incidence rate of PTT injuries has been reported to be approximately 12–13 per 1000 athlete days at the 2012 Summer Paralympics, with the overall injury incidence rate being 12.7 [18]. Para-table tennis athletes reported 40 injuries (out of 226 athletes), 47% were acute injuries and 45% were overuse injuries, with the remaining 8% being acute or chronic injuries [18]. In another Paralympic study, 69% of PTT players acquired an injury during training or competition [27]. PTT is generally considered low risk for injury compared to other Paralympic sports [26].

The types of injuries acquired during PTT are often included and not listed separately from other wheelchair sports or Paralympic sports [25].

Able-Bodied Table Tennis Injuries

There is minimal literature available on table tennis injury epidemiology. From the literature available, table tennis players appear to have a lower incidence of injury compared to other racquet sport players, such as tennis and badminton [36]. In a study of 29 table tennis players, 39 tennis players, and 15 badminton players, table tennis players had the highest number of shoulder injuries (20.05%) [36]. Shoulder injuries were followed closely by injuries of the spine, hip, and ankle in table tennis players. Ankle injuries, although common in all racquet sports, were less frequent in table tennis (~12%) compared to tennis (~20%) [36]. Infrequently injured sights included the forearm, fingers, head, and neck [36]. It was more likely that injuries would occur during competition or in the middle of a training process. Most injuries consisted of muscle tissue, joint, and tendon injuries [36]. One study looked at more chronic injuries and determined that ex-elite table tennis players had increased evidence of knee osteoarthritis on imaging [60]. Other common injuries for racquet sports include lateral epicondylosis, rotator tendinopathy, overdevelopment of the dominant arm, forearm nerve entrapments, low back pain, abdominal wall sprain, and tennis leg and eye injuries [36].

Injury Prevention in Para-table Tennis

For injury prevention in the para-table tennis player, like with other adaptive sports, it is very important to have the athlete undergo a physical exam and functional testing. For example, often racquet sport athletes only experience pain with skill execution, and normal physical testing may fall short of detecting and preventing pathology [36]. Recall that since able-bodied table tennis players may be at higher risk for shoulder injuries compared to other able-bodied racquet sports, it may be that PTT players are at an increased risk as well. Such risk may be secondary to the lack of a swingphase seen in the frequent PTT plays since a swingphase creates ideal joint angles of the shoulder, elbow, and wrist [36]. Therefore, it is especially important to consider shoulder rehabilitation for these athletes and to focus on the requirements of the shoulder with regard to specific skill demands in that player [36].

Injury Prevention for Wheelchair Sports (General)

As stated previously, all athletes should undergo a thorough physical examination and a task-specific performance evaluation to help identify areas prone to excessive load. This could possibly help to diagnose and prevent sports injury mechanisms [36] [61].

In general, since wheelchair athletes are more likely to develop upper limb injuries, it is not unreasonable to address range of motion and strengthening of the upper body. This includes the upper back, shoulder, and scapular muscles in all wheelchair athletes [47, 48]. Injuries in the upper limb may be due to the repetitive use of the upper extremities for wheelchair propulsion and overhead activities (in both everyday life and sport). For example, repetitive wheelchair propulsion mechanics encourage repetitive protraction of the scapula, leading to altered posture, weaker scapular stabilizers, and tightening of anterior shoulder muscles [49]. This may place the upper limb at increased risk for microtrauma and subsequent overuse injuries, like tendinopathies [30]. The "lack" of the entire kinetic chain during sports-specific tasks (like with racquet sports and throwing sports), and its role with regard to injuries, likely varies per wheelchair sport [10, 12].

The physician should also make sure that shoulder injuries are prevented "off the court." For example, there is already a higher incidence of rotator cuff tears in wheelchair users compared to non-wheelchair users, which may mean the wheelchair athlete is at even higher risk for rotator injuries [51, 52]. In order to prevent injuries "off the court," transfers and wheelchair propulsion should be monitored if applicable [53]. Physical therapy or occupational therapy should be considered for athletes who are at risk for injuries due to poor range of motion and improper technique seen with everyday functional tasks.

To expand on wheelchair ergonomics, assessment of the wheelchair in use may also help identify risk for nerve entrapments and spine injuries [39]. For example, nerve entrapments are likely secondary to hand-rim mechanics causing repetitive trauma to the nerves at the wrist or elbow [23]. It would not be unreasonable to consider orthotics as needed to try and prevent such entrapments. The spine may also be at risk for injury due to atypical seating position in wheelchair athletes. For example, spinal cord athletes typically sit with a posterior pelvic tilt and increased kyphosis of the thoracic spine and demonstrate a head forward position [30]. This may place inappropriate stress on the spine and lead to microtrauma and degeneration within the spine. All wheelchair modifications that can be made, without violating chair guidelines within each sport, should be considered.

Lastly, spinal cord athletes and cerebral palsy athletes have independent patterns of meeting energy demands during exercise (may not be anaerobic sources for power), and it is recommended that each strengthening program (such as intensity and frequency) be tailored toward the individual athlete's impairments [54]. For sport-specific injury prevention, refer to individual sections when available.

Summary

Para-table tennis includes and classifies athletes with both lower limb and upper limb impairments, not requiring lower limb impairments and wheelchair use, unlike the other sports discussed in this chapter. There are 11 athlete classifications, the first 5 classes use a wheelchair and classes 6–10 compete standing. The 11th class is for athletes that meet PTT classification but also have an intellectual impairment. The game follows similar rules of able-bodied table tennis, with minor exceptions, including not having to alternate turns during doubles play. The sport is relatively safe and has an incidence rate of injuries that is average when compared to other summer Paralympic sports.

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Adaptive Volleyball

20

Nicole Hanrahan and Arthur Jason De Luigi

Introduction to the Sport and Game Characteristics

Volleyball is an exciting and fast sport where two teams compete on a playing court divided by a net. In general, the goal is to ground the ball on the opponent's court and to prevent the opposing team from grounding the ball. The sport requires keeping the ball "flying" with a combination of fluid movement, explosive action, and teamwork. The rotation system inherent to the sport allows all players to operate both at the net and on the back court. The sport of volleyball has been easily adapted for persons with disabilities. Adaptive volleyball has utilized a similar structure of play, however, the competitors are in a seated rather than standing position and, therefore, also referenced as sitting volleyball. Recent updates on player positions and service, which mirror those of nonadaptive volleyball, have enhanced the tactical and technical elements of the game. Sitting volleyball also allows for integration of able-bodied athletes with disabled athletes at the non-international level of competition [1].

The different versions of the game serve to accommodate various player circumstances and abilities. This serves to increase versatility and allow the game to be played by those of many different skill sets and functional levels. It is also one of the only adaptive sports where athletes do not rely on special technology or equipment to participate, making the sport readily accessible to everyone.

The roots of adaptive volleyball date back to the 1950s, where the sport was used to rehabilitate World War II veterans [2]. Originally, the sport was divided into two adaptive disciplines: sitting volleyball and standing volleyball. Sitting volleyball emerged from a combination of volleyball and a German game called Sitzbal, which was created in 1953 [1, 3]. The Paralympics debuted standing volleyball at the 1976 Toronto Games, and then sitting volleyball was introduced at the 1980 Games in Arnhem, Netherlands [4]. Since the creation of sitting volleyball, it has grown to become one of the biggest sports in the world. Men's competitions dominated the sport until the 2004 Games in Athens, when the first Paralympic women's sitting volleyball competition was held [4]. The 2004 games in Athens also marked the first time where only sitting volleyball was on the Paralympic program. This trend has

N. Hanrahan, MD (✉)
Palomar Medical Center Downtown Escondido, 555 East Valley Parkway, Escondido, CA 92025, USA
e-mail: nicole.f.hanrahan@medstar.net

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA
e-mail: ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_20

continued for both the Beijing 2008 and the London 2012 Paralympic Games [1].

In the USA, sitting volleyball is governed by the World Organization of Volleyball for the Disabled, which is affiliated with the International Paralympic Committee. In the Paralympic arena, there are regular major international championships as well as zonal tournaments as a qualification for the Paralympics [3]. Each Paralympics comprises of ten sitting volleyball men's teams and eight sitting volleyball women's teams. These teams represent the top three teams from the world championships, the winner of each of the four zones (European Zone, Americas Zone, African Zone, and Asian Oceanic Zone) and a team from the host nation. In the men's division, the two additional teams are now allocated from a fifth zone (sub-Saharan Zone), along with the top-ranked team from the Intercontinental cup.

Eligible Players/Classification

All athletes with physical impairments are eligible. Prior to participation in sitting volleyball, athletes must undergo a formal classification process by a classifier. Classifiers must be accredited for state, national, and international classification to participate in the process. The volleyball classification system is based on the "Amputee and Les Autres" system used by the International Sports Organization for the Disabled (Fig. 20.1). The process consists of three elements: the physical examination, the motor examination, and observation. A classification passport is issued to athletes after the classification process has been completed and is valid for 4 years [3].

Players are assigned a classification of either minimally disabled (MD) or disabled (D; also known as full disabled). Classification is conducted using one or more of the following measures: muscle strength, amputation level, range of motion of multiple joints, limb paralysis, and differences in limb length. In general, athletes with a disability tend to have major acquired or congenital impairments, including any impairment that can affect an individual's body control. Minimally disabled athletes generally are unable to play able-bodied volleyball due to long-term chronic injuries [6].

For international sitting volleyball competitions, teams may only have two minimally disabled players on the roster and only one minimally disabled player on the court at any given time. The six players on the court must fulfill this requirement at all times, even when a Libero is on the court. A full roster consists of a total of 12 players, with 6 players allowed on the court at any given time [7].

Rules [7]

Similar to standing volleyball, sitting volleyball involves playing a total of 5 sets to 25 points each using rally scoring with a minimum lead of two points needed to win the set. The match is won by the team who wins three sets. In some domestic and club tournaments, however, the winner is the best of three sets. In the case of a 2-2 tie, the deciding fifth set is played to 15 points with a minimum lead of two points needed to win the set. In order to put the ball into play, a serve is sent into the opponent's court over the net by the server. The basic pass-set-spike combinations are essential in all versions of the sport.

Despite the general principles being similar, there are some differences in sitting volleyball as compared with standing volleyball. First, when striking a ball, part of the player's torso (measured from buttocks to shoulders) must remain in contact with the ground. Second, a player's legs may cross the service, attack, and center lines as long as there is no interference with an opposing player. Third, blocking or attacking a serve is legal in sitting volleyball. The pace of sitting volleyball at the competitive level is noted to be as fast as or faster than that of standing volleyball.

Special Positions [7]

Coach

Before the match, the coach records and/or checks the names and numbers of the players on the score sheet and then signs the score sheet.

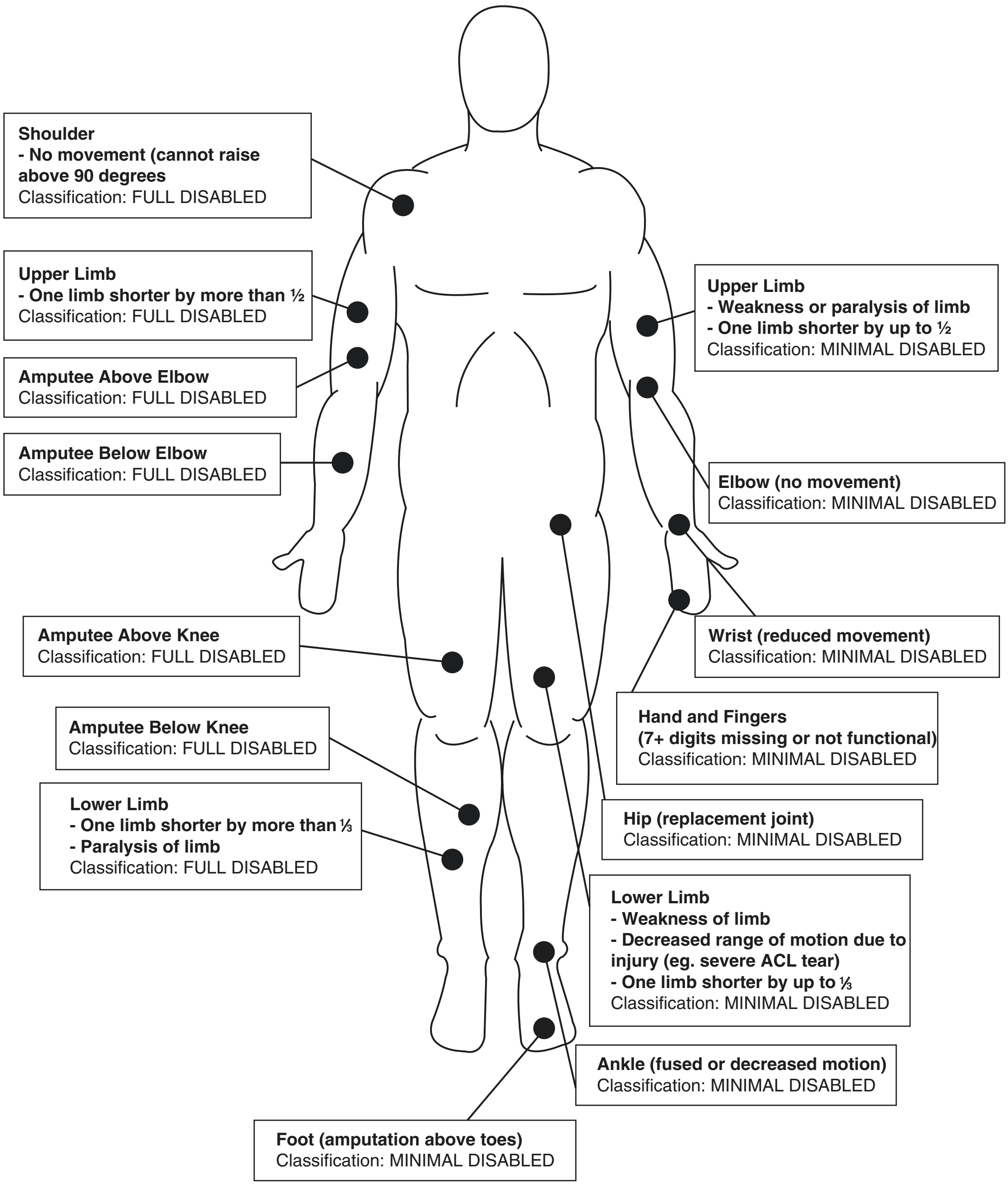

Fig. 20.1 Classification Figure for International Sitting Volleyball. Adapted from Volleyball Canada [5]

During the match, the coach provides the second referee or scorer with their lineup sheet. The coach also requests time-outs and substitutions and may give instructions to players while in the free zone in front of the team bench without interrupting or delaying the match. In World ParaVolley Official Competitions and Zonal Championships, a coach's restriction line is added and the coach may only perform his/her function behind this line.

Assistant Coach

The role of the assistant coach is to assume the coach's function during a coach's absence once approved by the referee. The assistant coach sits on the team bench but may not intervene in the match in any way.

Team Leader (Captain)

Before the match, the team captain is responsible for signing the score sheet and representing his/her team in the coin toss. During the match, the captain may speak to the referees for interpretation of game plays, to ask for authorization to change or check equipment, and in the absence of the coach, to ask for time-outs and substitutions. The team captain signs the score sheet again at the end of the match to endorse the final result and has the right to record an official protest regarding the referee's application or interpretation of the rules during the match.

Libero

At the start of the match, each team may designate up to two Liberos who act as defensive specialists. Only one Libero is allowed on the court at any time. The Libero may replace any of the players in a back-row position and is not allowed to complete an attack hit from anywhere if at the moment of contact the ball is entirely above the net. He/she may not serve, set in the front row, block, or attempt to block. Libero replacements are not counted as substitutions and are unlimited. The Libero must wear a uniform, jacket, or bib of a different dominant color from the color of the rest of the team, and it must clearly contrast with the rest of the team's uniforms. These rules are similar to that of traditional volleyball.

Equipment [7]

Playing Area

The playing court and the free zone around the court should be rectangular and symmetrical. The playing court itself measures 10 m × 6 m and is surrounded by a 3 m free zone on all sides (Figs. 20.2 and 20.3). A free playing space above the playing area should be free from any obstructions and be at least 7 m above the playing surface. The court is surrounded by boundary lines that are 5 cm wide and of a light color that is different from the court.

A center line dividing the playing court into two equal courts is marked underneath the net from

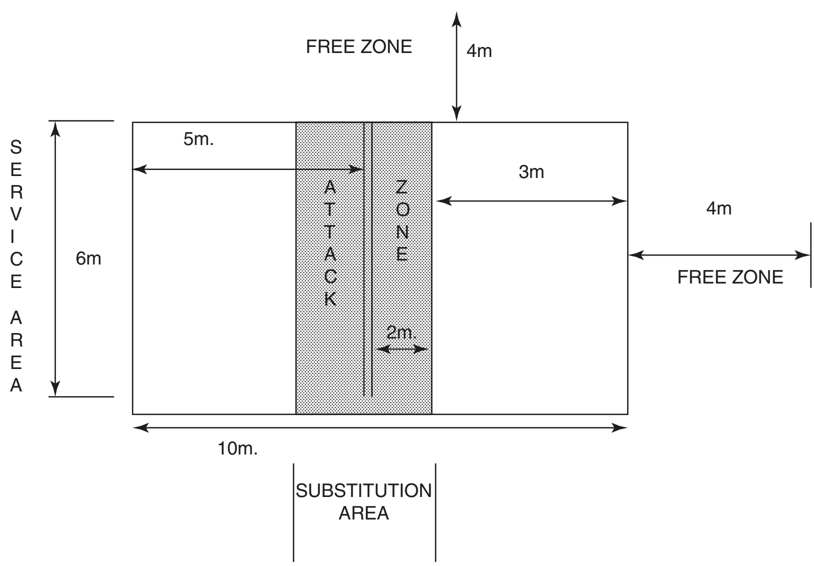

Fig. 20.2 Playing Area Dimensions, simplified. Adapted from National Center on Health, Physical Activity and Disability [2]

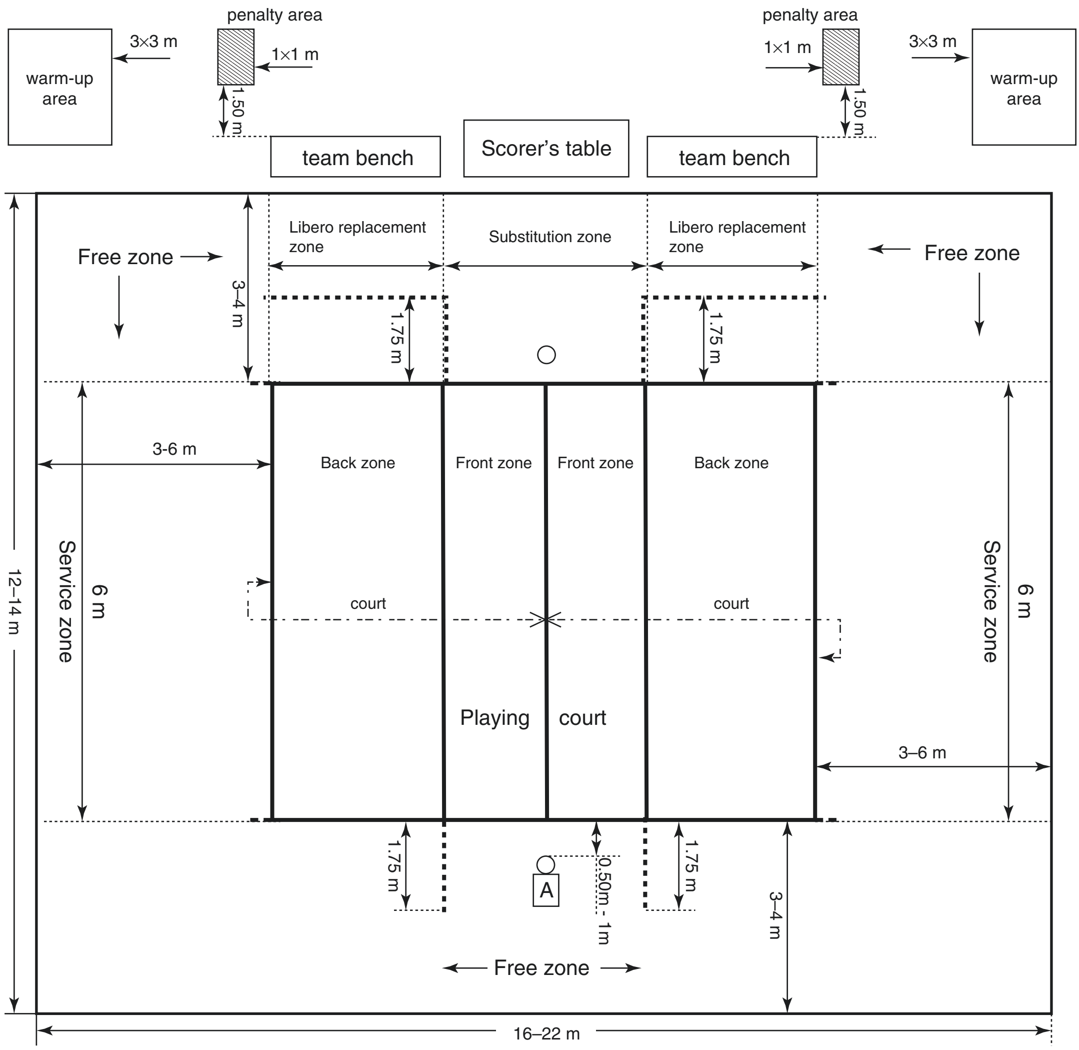

Fig. 20.3 Playing Area Dimensions, detailed. Adapted from World ParaVolley Official Sitting Volleyball Rules 2013–2016 [7]

side line to side line. There is also an attack line drawn 2 m back from the axis of the center line, which delineates the front row from the back row.

Playing Surface

The indoor playing surface should be flat, level, and uniform and should not present any risk of danger or injury to players. It is forbidden to play on rough or slippery surfaces. Indoors, the court's surface must be of a light color. On outdoor surfaces, a slope of 5 mm per meter is allowed for drainage. Lines made of solid materials are forbidden.

Net, Posts, and Antennae

The net is placed vertically over the center line, with a height of 1.15 m for men and 1.05 m for women. The net height over the sidelines must be exactly the same and may not deviate from the official height by more than 2 cm. There are two horizontal and two side bands made of twofold

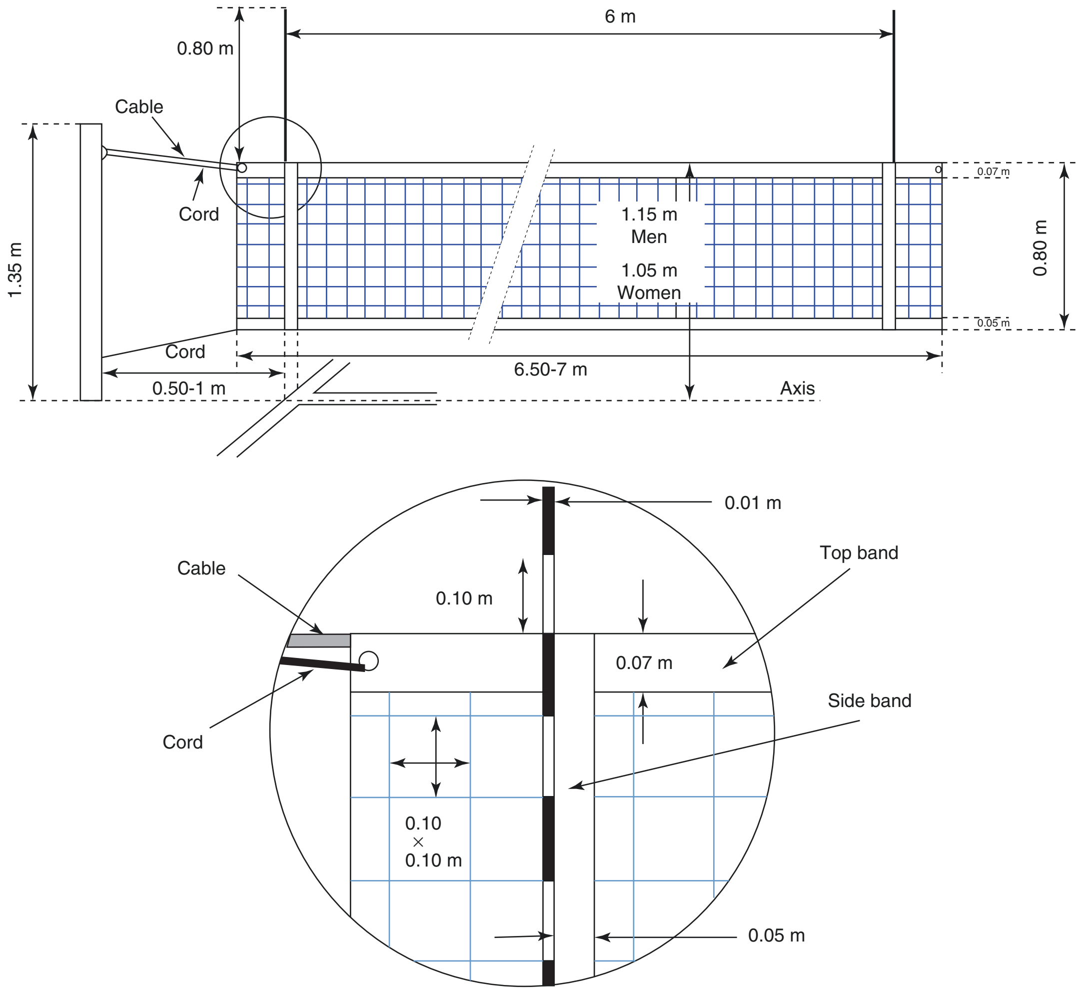

Fig. 20.4 Net, Post and Antenna Measurements. Adapted from World ParaVolley Official Sitting Volleyball Rules 2013–2016 [7]

white canvas are fastened to the net, and a flexible antenna is then attached to the outer edge of each side band (Fig. 20.4).

Balls

The ball should be made of a flexible leather or synthetic leather case with a rubber or rubberized bladder inside. There are circumference, weight, color, and pressure standards to which the balls must adhere. In World ParaVolley Official Competitions and Zonal Championships, three balls are rotated in, with six ball retrievers positioned strategically around the corners of the free zone and behind the referees.

Players' Equipment and Uniforms

The Libero must wear a uniform, jacket, or bib with a different dominant color from that of the other team members. Players may play without shoes with authorization from the first referee. For World ParaVolley Official Competitions and Zonal Championships, it is forbidden to play barefoot (without socks).

Change of Equipment

Players may change damaged or wet uniforms after a substitution or between sets as long as the color, number, and design of the new uniform are the same. Players may also play in warm-up training suits in cold weather, provided that they are of the same color and design for the whole team (other than the Liberos; see above).

Prohibited Objects

While there are no prohibited objects, it is not recommended that lower extremity prosthetics are worn during sitting volleyball. This is not only because prostheses tend to limit speed and mobility on the court but also for other players' safety. Users of prosthetic arms, on the other hand, may use upper extremity prostheses for passing, serving, and blocking. Players may not sit on thick material or wear specially padded or thickened shorts or pants.

Common Injuries

In volleyball players, the rate of overuse injuries averages 0.6/1000 playing or practicing hours, with the most common injury overall being ankle sprain (41%) [8]. These statistics apply to players of all ages and abilities, however. A review of the literature reveals a dearth studies focusing on injuries specific to adaptive volleyball but some injuries are included in large epidemiologic studies such as the 2012 London Summer Paralympic Games [9].

Zerger [10] contends that the lower half of the body is more static compared with the upper half in sitting volleyball, and thus upper extremity injuries, especially shoulder injuries, tend to be the most common. The specific types of overuse injuries, including impingement syndromes, rotator cuff tears, and labral damage, are similar to those of able-bodied volleyball players. One must also remain aware of the fact that sitting volleyball players use their arms and shoulders not only for game play but for propulsion across the court. In addition, sitting volleyball players who use wheelchairs off the court may be more prone to shoulder injuries given the increased risk for muscular imbalance and overuse inherent with prolonged wheelchair use [10].

In contention with the claim that shoulder injuries are the most common in adaptive volleyball players, Reeser's study, based on a retrospective self-report by standing volleyball players, noted that ankle injuries were in fact the most common (21%) [11]. The shoulder, wrist, and hand accounted for 18% and the knee another 14% of injuries [11].

Low back pain has also been cited as a common area of injury, as well as sprains of wrists/fingers [3]. In 2001, Melzer et al. concluded that there is an increased prevalence of knee arthritis in the sound limb of male amputee adaptive volleyball players compared with matched controls [12].

As evidenced above, adaptive volleyball injury studies have conflicting results as to the most common pathology encountered. In addition, literature prior to 2004 (the start of the trend toward only sitting volleyball) also includes injuries sustained by standing volleyball players. The two different types of the sport may in fact have different mechanisms and types of injuries. There is much variability in the research designs, definitions, and approaches to the study of disabled athletes in general, and only in the last 20 years or so has it become a well-studied topic [13]. Sports medicine personnel, staff, and coaches would also benefit from data; for example, a screening tool could be implemented to evaluate players and their risk for injury.

Conclusion

In conclusion, adaptive volleyball appeals to both players and spectators worldwide. It is a very inclusive sport that involves strategy, teamwork, strength, and finesse at the same time. Whether a beginner or at the Olympic level, young or old, sitting volleyball can be played by all. As the sport continues to grow in popularity and number, it is important that physicians be aware of the nuances of the sport, and more research is needed to enhance knowledge of both the mechanisms of injury and their treatment.

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21 Adaptive Water Sports

Simon Willis, Alan Schleier,
and Arthur Jason De Luigi

Introduction to Adaptive Water Sports

The options for participation in adaptive water sports are vast and range from small equipment adaptations to Paralympic level sporting competition. For the purposes of this chapter, we will focus on swimming, rowing, and sailing as these sports are represented at levels ranging from amateur/club sports up to the Paralympic level. We however will also touch on a few pertinent points regarding participation in more casual forms of water sports. The objective of this chapter is to provide a knowledge foundation so that clinical care providers may feel prepared and confident in providing care at adaptive water sports events and for athletes who participate in these sports.

S. Willis, MD, PGY-3 (✉)
MedStar National Rehabilitation Hospital,
MedStar Georgetown University Hospital,
Washington, DC, USA
e-mail: smwillis703@gmail.com

A. Schleier, DO
Sports Medicine Center, NYU Langone Medical
Center, New York, NY, USA
e-mail: alan.schleier@gmail.com

A.J. De Luigi, DO
Department of Rehabilitation Medicine,
Georgetown University School of Medicine,
Washington, DC, USA
e-mail: ajweege@yahoo.com

The obvious difference between adaptive water sports and other adaptive sports is the presence of water. In addition to medical and safety concerns applicable to providing care to all disabled athletes, the introduction of water presents its own set of considerations. Therefore, it is imperative for the medical staff to be prepared for illness and injuries that are both common within all aquatic-based sports as well as pertinent to each individual sport. Most importantly, careful attention to athlete safety must be taken into consideration in regard to increased potential of drowning with a strong understanding of athlete resuscitation and plan of action for drowning participants.

Adaptive Rowing

Background

Adaptive rowing is a sport that is represented from the recreational club level all the way up to the Paralympic level. Adaptive rowing was born in Philadelphia after World War II when blind veterans competed in a rowing race between the Army and Navy. In the following decades, adaptive rowing continued to grow at a grassroots level until 1980 when the Philadelphia Rowing Program for the Disabled was formed. It wasn't until 2002, however, that adaptive rowing was included in the FISA World Championships and finally in 2008, the first Paralympic competition

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_21

was held at the Beijing games [1]. It offers a great opportunity to participate in an individual and team sport with a great deal of both physical and mental benefit. Rowing is an excellent form of cardiovascular exercise, provides increased strength and flexibility, can improve confidence, and provides opportunity to socialize and participate with both disabled and non-disabled athletes. Adaptive rowing is suitable for disabled athletes with a wide range of conditions including stroke, brain injury, spinal cord injury (SCI), amputation, visual impairment, hearing impairment, cerebral palsy, autism, cognitive impairment, post-traumatic stress disorder (PTSD), and epilepsy. Rowing can be particularly attractive to athletes with visual impairments as they may row in a boat guided by a fellow athlete without visual impairment. It is also particularly suitable for athletes with impairments limited to the lower extremities, as stroke mechanics may be adapted for athletes to use their arms and torso or even arms only.

There are two major styles of rowing, sweep and skull rowing. In sweep rowing, each rower in a boat pulls a single oar. In this configuration, each boat carries even numbers between two, four, and eight rowers, all situated with alternating left/right orientations of their oars. These oars tend to be longer and are traditionally pulled using both upper extremities. With sculling boats, each individual rower pulls two shorter oars, traditionally one in each hand. In adaptive rowing, a distinction is made between "cross" sculling where the handles of the oars are longer and may intersect and "uncrossed" sculling where shorter oars are used and do not have the potential to cross or hit each other. Boats may carry a coxswain or be "coxless." A coxswain is a member of the crew who acts like a coach on the water as well as the captain of the boat. They are typically lighter-weight individuals in order to limit their weight burden on the boat and are responsible for coordination of the crew as well as steering of the shell using a small rudder. The coxswain is seated either at the front (fore) or rear (aft) of the shell and will typically wear a headset microphone wired to a speaker system running throughout the shell so that their instructions may be heard by the rowers.

Classifications

Adaptive rowing classifications include leg, trunk, and arms (LTA), trunk and arms (TA), and arms and shoulders (AS). LTA may be further divided into LTA-PD (physical disability; LTA-B1, LTA-B2, and LTA-B3 pertaining to visual impairment) and LTA-ID (intellectual disability). The LTA classifications employ typical rowing mechanics and do not restrict use of a sliding seat, hips, or flexion/extension of the torso. Athletes typically competing under the LTA classification include athletes with unilateral amputations of the upper or lower extremities, neurological impairment equivalent to an incomplete S1 lesion, unilateral upper extremity neurological impairment, cerebral palsy (class 8), and the visual impairments. Athletes must be able to support themselves on a sliding seat in order to participate at the LTA level. If an athlete is able to perform a full squat and return to a standing position, they will likely be assigned into the LTA classification [2].

The trunk and arms class is suitable for athletes who retain trunk function but are unable to use a standard sliding seat due to impairments involving the lower extremities. Examples of athletes in this category are those with bilateral lower extremity amputations, impaired knee extensor strength, neurologic impairment equivalent to an incomplete L1 lesion or a complete L3 lesion, and cerebral palsy (class 5). The arms and shoulders (AS) class is reserved for athletes who have impaired trunk function and will typically also have impaired sitting balance. These rowers utilize arm and shoulder strength as means of oar propulsion and use a fixed seat with torso straps for stabilization [2]. AS rowers will typically have impairments equivalent to athletes with complete T12 lesions, an incomplete T10 lesion, or cerebral palsy (class 4) [2]. Table 21.1 describes the classifications for the adaptive rowing for athletes without visual deficits.

In the classification of visually impaired athletes, placement into LTA-B1, LTA-B2, and LTA-B3 categories depends on the level of visual impairment with best correction, certified by an optometrist or ophthalmologist. Classifications for the LTA-visually impaired (VI) athletes are listed in Table 21.2 [2].

Table 21.1 Classifications for adaptive rowing [2]

LTA: leg, trunk, and arms	Athletes who are able to use their legs, trunk, and arms to propel the boat as well as are able to use the sliding seat. Can be further broken down into LTA-visually impaired (VI) and LTA-intellectually disabled (ID). LTA-VI is a classification of athletes whose abilities are similar to standard LTA; however, they also present with visual impairments which will be further subclassified in Table 21.2. Similarly, LTA-ID represents a subset of LTA athletes that also have concomitant intellectual disabilities
TA: trunk and arms	Athletes who are able to use their arms and trunk during the rowing process, however, are unable to use their legs or a sliding seat during the progression of the stroke. Typically athletes have good truncal control and arm function
AS: arms and shoulders	Athletes who are able accelerate the boat using primarily their arms and shoulders. These athletes have minimal to no leg and trunk function

An athlete with a left below-knee amputation sculling with the use of her prosthetic. This athlete is classified as an LTA rower (Photo courtesy of Alan Schleier)

Equipment

There is a myriad of equipment adaptations seen in adaptive rowing. Their designs are based on goals of both improving safety and facilitating effective stroke mechanics for the athlete. Every part of a rowing setup, including the boat body itself (shell), oarlocks, footplates, and seating, may be modified. In most cases, the use of pontoons is also required to increase the stability of shells. Additional equipment involved in seating, padding and support, transfers, communication aids, and prosthetic accommodations may also be employed. There are even modifications to land-based training equipment (ergonomic rowing machines) which may be used to accommodate an individual athlete's needs. If racing under the Fédération Internationale des Sociétés d'Aviron (FISA) rules, LTA-VI rower must wear light occluding goggles during warm-up, training, and competition.

Table 21.2 Classifications for adaptive rowing for athletes with visually impairments (VI) [2]

LTA-B1	No light perception in either eye to light perception, but inability to recognize the shape of a hand at any distance or in any direction
LTA-B2	From ability to recognize the shape of a hand to a visual acuity of 2/60 and/or monocular visual field of more than 5° and less than 20°
LTA-B3	From visual acuity about 2/60 to visual acuity of 6/60 and/or monocular visual field of more than 5° and less than 20°
N/E	Visual acuity over 6/60 and/or monocular visual field of more than 20°

An athlete with a spinal cord injury (*right*) rowing with a non-disabled athlete (*left*). Note the adapted seating, which contains both a seat back and torso straps. This athlete competes within the TA classification (Photo courtesy of Alan Schleier)

An arm/shoulder setup for a sweep rower including fixed seat and pontoon (Photo courtesy of Alan Schleier)

Adaptive Sailing

Background

Adaptive sailing has been part of the Paralympic Games since 1996 [3]. The first occurrence consisted of one event with a mixed crew boat. It was initially contested as a demonstration event and not an official part of the games, although medals were awarded to the first Paralympic sailors. In 2000, adaptive sailing became an official part of the Summer Paralympic Games with two events being represented in Sydney. The first was a one-person keelboat using the 2.4mR and a three-person keelboat using the Sonar. The SKUD 18 class of sailing debuted in Qingdao, China, in 2008 during the Paralympic Games with 11 nations competing on the two-person keelboat [4].

Athletes with disabilities due to spinal cord injury, brain injury, stroke, amputations, cerebral palsy, visual impairment, hearing impairment, and intellectual disability may all participate in sailing with different levels of adaptation. However, adaptive sailing itself is a multi-disability sport in which athletes with differing types of impairments can compete together on the same vessels or against one another. At the Paralympic level, three sailing classes exist: the 2.4mR, SKUD 18, and Sonar [3, 4]. These classes of adaptive sailboats are raced with 1, 2, and 3 sailors aboard, respectively. A further detail regarding the type of boats raced in each class is listed below in Table 21.5. Paralympic sailing classification is based on three factors including stability, hand function, and mobility [3]. Athletes are ranked according to a point system awarded based on severity of disability with the lower points corresponding to severely impaired and the higher points for the less disabled. The awarded points range from 1 to 7, with 1 corresponding to the lowest level of function to 7 being the highest. Furthermore, each individual boat uses its own point system to make up a team. Athletes in a single-person boat have to meet a minimum criterion of a classification ranking 1–7. The two-person boats require one of the two sailors having a number of 1 or 2 with the other crew member having any classification from 1 to 7. Furthermore, of the 2 crew members must be female. In the three-person boat, each team of sailors is allowed a maximum of 14 points to allow for equal competition [3]. Athletes with visual impairments have a separate classification procedure for adaptive sailing. They are placed into 1 of 3 competition rating classes based on visual acuity and field of vision [3]. Depending on the athlete's visual capabilities, they are placed in a sport class of 3, 5, or 7. In this system 7 indicates the highest eligible visual ability. Table 21.3 describes the classification system for the visually impaired athletes.

Adaptations may include use of transfer systems, adaptive seating and support systems, communication systems, and alterations to the sailing vessel itself that may alter how the sails

Table 21.3 Classification for visually impaired athletes in adaptive sailing [5]

B1	Total absence of perception of light in both eyes or some perception of the light but with the inability to recognize the form of a hand at any distance and in any direction
B2	A visual ability to recognize the form of a hand to a visual acuity of 2/60 and/or visual field of less than 5°
B3	A visual acuity of above 2/60 to a visual acuity of 6/60 and/or a visual field of more than 5° and less than 20°

and/or the steering fin (rudder) are manipulated. Additional methods of increasing safety during transfers may also be employed. In addition to any access ramps, lifts, stability mats, or other equipment that will enable a disabled sailor to reach a vessel, measures should be taken to maximize safety during transfers [5]. For instance, when a disabled sailor is boarding a vessel from a dock, it is important to remove bumpers in order to allow the boats body (hull) to be as close to the dock as possible, therefore decreasing the space a sailor must traverse to board the boat. Also, it is important remove any stray ropes (lines) from the boarding area that may present a safety hazard or otherwise interfere with transfer.

Equipment

The major adaptations seen within sailing correlate with boating vessels themselves. There are a number of sailing vessels that are used in adaptive sailing, and the most commonly used vessels are included in Table 21.4.

Once aboard, a disabled sailor may utilize a number of adaptations to the cockpit environment. In terms of safety, special seating, harnesses, and/or stability straps may be used. Additional nonskid surfaces and added handles and grips may be added to the deck and cockpit surfaces to further add to sailor stability. For vessel operation, a number of adaptations may be made to equipment. For sailors with unilateral upper extremity impairments, alteration to cleats may be made for improved ability to operate one handed. Tillers, long steering bars which attach to a steering "fin" below the water known as the rudder, can be modified by alteration length or addition of rings or handles to assist a captain in steering the vessel. For those sailors with more advanced impairment of the upper extremities, joystick controls combined with electric winches and/or servo-assisted tillers may allow for both sail and rudder manipulation [5]. In cases where sailors have very limited or absent upper extremity function,

Table 21.4 Sailing vessels used in adaptive sailing [5]

Access 2.3	A single-crew cat rigged 7′ 6″ sailing keelboat. It is regarded as a beginner's dinghy. It can be controlled via joystick rather than a tiller and c is seated facing forward. The crew does not switch sides during a tack. Its design is composed of a low ballast and high sides, and it can be equipped with servo assist electric controls to assist with athletes with physical impairments
Access 303	A single or two crew 10′ sailing keelboat. It is regarded as a beginner's dinghy. It can have similar joystick control to Access 2.3 also with the crew facing forward. It has the same electric servo-assisted drives as Access 2.3 also is designed with a low ballast and high sides. The rigging is raised with an added jib, creating an extra sail to trim
Access Liberty	Similar to the Access 2.3 and 303, the Liberty is long at 12′ and was designed to be faster and high pointing
SKUD 18[a]	A two-person lead-assisted 19′ skiff with a tube-launched asymmetrical and modern high performance stayed rig. Helmsperson can transfer manually and be steering with tillers. Otherwise helmsperson can be in a fixed seat on the centerline using a manual joystick, push/pull rods, or a servo assist joystick with full control of all functions. The forward crew can either be seated on the centerline, transferring manually, or on trapeze. It is one of the three classes of adaptive racing sailboats used in the Paralympic Games. Criteria for the SKUD 18 class require at least one member of the crew to be female
Freedom 20	A 20′ 6″ keelboat with two mounted pivoting seats. One seat is for the helmsman and the other for the forward seated crew. It has a low freeboard and orderly side decks for easy onboarding and maneuverability. The ballast ratio and vertical center of gravity gives added stability. Equipped with self-tending jib and efficient rigging
Hobie Trapseat	Two-hulled 16′ 7″ catamaran made for a two-person crew. The "trapseats" are bolted onto either side, allowing for one crew member to steer the boat with the tiller and the other to man the main sail and jib. It offers people with severe disabilities the opportunity to sail on even-terms with an able-bodied crew member. Often utilized by Special Olympic sailing programs

(continued)

Table 21.4 (continued)

Norlin Mark III 2.4mR[a]	A 13′ 8″ single-handed dinghy that is well suited for all types of physical impairments as the sailor does not need to move about the boat. The control lines are fitted under the deck to a console directly in front of the sailor allowing for easily adjustable controls. Utilizes a hand tiller for steering and/or a foot pedal steering if required. It has no spinnaker but does use whisker pole for setting the jib downwind. It is considered one of three classes of adaptive racing sailboats in the Paralympic Games and has been used in every Paralympics since Sydney 2000
Martin 16	A 16′ 0″ keelboat that can be navigated by one to two crew members. It has a weighted high lift keel which makes it a very stable and safe. It can be easily trailer launched and rigged by one person adding to its easy usage and stability. It has adjustable seating and a specialized control system with optional automated systems for steering, including manual or electronic joysticks or sip and puff, automated sheeting as well as bilge pumping
Sonar[a]	A three-person 23′ keelboat with a contoured sit-in, large cockpit, and numerous configurations for adaptations. It is Bermuda rigged and has a large mainsail. It is one of three classes of adaptive racing sailboats used in the Paralympic Games and was one of the first boats sailed at the 1996 Paralympic Games. It is sailed without a spinnaker and utilizes a whisker pole to hold the jib out when running downwind
Flying Scot	A one-design, day sailor dinghy that has a sail plan consisting of a main, jib, and spinnaker. The simple rigging and uniform wide beamed construction has made it one of the most popularized boats
Ideal 18	A newer design keelboat that has eats, seat backs, cockpit floor, and splash rail is built into the deck mold. It can be fitted with special adaptations that are particular to any athlete-specific requirements
Challenger Trimaran	A 15′ single-handed vessel whose class association permits sailors with disabilities to adapt their boat to their own preferences. Modifications to seating and control line setup are nearly always allowed. A very tough and stable craft

[a]Type of adaptive sailing racing class in the Paralympic Games

sip and puff systems similar to those used with power wheelchairs may be used to both trim (pull in/out) sails and steer the tiller [5]. Ropes, loops, and grips are equipment that are commonly added to the vessels and employed to aid the sailors in holding on for stability.

Adaptive Swimming

Background

Adaptive swimming is one of the most popular sports among disabled athletes with one of the highest participation rates. Since the first Paralympic Games in Rome, Italy, in 1960, it has remained a staple in the games drawing some of the greatest interest from participants to spectators. The 2012 Paralympic Games in London, England, saw one of the most impressive number of participants, including 148 medal events with 600 athletes, 340 of which were men and the remaining 260 being women [6]. Competitions are held in 50-m pools and swimmers are not allowed to don prostheses or assistive devices during competitive events per Paralympics guidelines. Events are open to both male and female athletes with physical disabilities including dwarfism, amputation/limb loss, blindness/visual impairment, spinal cord injury, and other wheelchair-bound ailments, cerebral palsy, brain injury, stroke, other cognitive impairments, and Les Autres [6]

Adaptive swimming, like many other adaptive aquatic sports, helps to develop both strength and flexibility. Much of the stress that would be placed on athletes during participation in contact sports is reduced, producing an activity that allows for both cardiovascular and musculoskeletal conditioning without the added degradation and worsening of already present physical impairments, including no impact forces through residual limbs in athletes with amputations. Furthermore, the water's buoyancy properties produce for an environment in which disabled swimmers are afforded the support of their body weight, without the added consequence of falling, often times helping to even the playing field among varying impairments.

The majority of the same rules apply for Paralympic swimming that apply to non-disabled competitions. Similar to non-disabled races, swimmers may begin races by standing on a platform and diving into the pool. Other athletes however may start in the water if their impairment limits them from standing and/or diving. Some strict rules do apply to adaptive swimmers who present with certain impairments. One such rule is no butterfly stroke or diving at the start of the race for persons with atlantoaxial instability. Similar to this, no diving is allowed for athletes if they have any sort of shunt in place. Furthermore, athletes who present with open wounds must be excluded from all competition as the risk for infection and further bodily harm is too great.

An adaptive swimmer classification may vary for different swimming strokes as their physical impairments may alter the way in which they are able to perform the certain strokes. However, unlike any other Paralympic sport, swimming is the only sport that combines varying impairments, including conditions of limb loss, cerebral palsy, spinal cord injury, Dwarfism, and other disabilities, across classes. The classification system allows for swimmers with certain impairments to compete against those with similar levels of function. Those with physical disabilities are placed in categories between 1 and 10, with 1 representing the most severely disabled. Blind and visually impaired swimmers are altogether categorized into a separate classification within categories 11, 12, or 13. Category 11 is relegated for athletes who are totally blind, while those in category 13 have severe visual impairment but are not completely blind. Swimmers with intellectual disabilities fall into class or category 14. In the adaptive swimming classification system, the prefix S denotes the class for freestyle, backstroke, and butterfly, while SB denotes the class for breaststroke, and SM represents the class for individual medley [6, 7]. Table 21.5 outlines the different classifications among disabled swimmers.

Table 21.5 Classification for adaptive swimming [6, 7]

S1 SB1 SM1	Swimmers in this sport class have a significant loss of muscle power or control in their legs, arms, and hands. Some athletes also have limited trunk control, as it may occur with tetraplegia. These impairments may be caused by spinal cord injuries or polio. Swimmers in this class usually use a wheelchair in daily life
S2 SB1 SM2	Swimmers in this sport class are able to use their arms with no use of their hands, legs, or trunk or have severe coordination problems in four limbs. As in sport class S1 SB1 SM1, athletes mostly only compete in backstroke events
S3 SB2 SM3	This sport class includes athletes with amputations of all four limbs. Swimmers with reasonable arm strokes but no use of their legs or trunk and swimmers with severe coordination problems in all limbs are also included in this sport class
S4 SB3 SM4	Swimmers who can use their arms and have minimal weakness in their hands but cannot use their trunk or legs. Athletes with amputations of three limbs also swim in this sport class.
S5 SB4 SM5	Swimmers with short stature and an additional impairment, with loss of control over one side of their body (hemiplegia) or with paraplegia, compete in this sport class
S6 SB5 SM6	This sport class includes swimmers with short stature, amputations of both arms, or moderate coordination problems on one side of their body
S7 SB6 SM7	This profile is designated for athletes with one leg and one arm amputation on opposite sides, double leg amputations, or a paralysis of one arm and one leg on the same side. Moreover, swimmers with full control over arms and trunk and some leg function can compete in this class
S8 SB7 SM8	Swimmers who have lost either both hands or one arm are eligible to compete in this sport class. Also, athletes with severe restrictions in the joints of the lower limbs could compete in this sport class

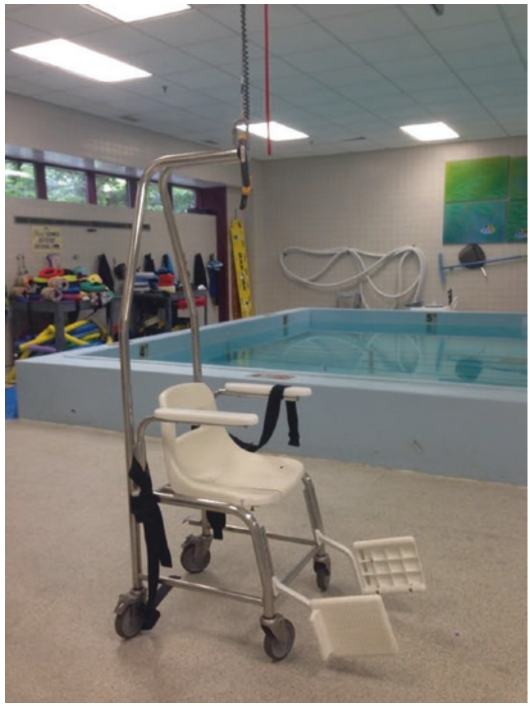
(continued)

Table 21.5 (continued)

S9 SB8 SM9	Athletes in this sport class swim with joint restrictions in one leg, double below-the-knee amputations, or an amputation of one leg
S10 SB9 SM10	This class describes the minimal impairments of eligible swimmers with physical impairment. Eligible impairments would be the loss of a hand or both feet and a significantly limited function of one hip joint
Sport classes 11–13: visual impairment	Swimmers with visual impairment compete in the sport classes 11–13, with 11 meaning a complete or nearly complete loss of sight and 13 describing the minimum eligible visual impairment. Athletes in sport class 11 compete with blackened goggles
Sport class 14: intellectual impairment	Swimmers with intellectual impairment who also meet the sport-specific criteria compete in sport class 14

Equipment

Prior to an athlete with a disability entering a pool, it is essential that the environment be made safe and navigable for the individuals and their team. Wherever possible, measures should be taken to increase traction and reduce the potential for slips and falls both in and around a pool. Most pools carry nonskid surfaces on the decks; however, further measures including nonskid ladders, mats, and platforms may be used. These can be especially helpful in maximizing the safety of transfers between the pool and pool deck. For some athletes, nonskid water shoes may be appropriate. As always, proper care taken of the pool deck is also important and should include ensuring the deck is kept as dry as possible and free of clutter. For transfers to and from the pool, there are various options to enable safe transfers and include ceiling lifts attached to submersible chairs, extra handrails, nonskid stairs, and padded nonskid mats.



A water-friendly transfer chair with ceiling-lift suspension (Photo courtesy of Alan Schleier)

A set of nonskid stairs, complete with handrails to assist with safe transfer in and out of the pool (Photo courtesy of Alan Schleier)

Cushioned nonskid steps leading to pool (Photo courtesy of Alan Schleier)

Therapeutic pool containing handrails (Photo courtesy of Alan Schleier)

Depending on an athlete's particular impairment, differing measures may be taken inside of a pool to aid in swimming mechanics and ensure safety. At the Paralympic level, only swimwear approved by Fédération Internatationale de Natation may be worn, though the IPC does allow for modifications to a swimmer's suit to accommodate a swimmer's individual impairment(s). Furthermore, personal floating devices (PFDs) may be utilized for athletes who have difficulty remaining buoyant. For visually impaired swimmers, the use of "tappers" may be employed to prevent swimmers from colliding with the end of the pool walls [6]. In these cases, poolside designees use a soft tipped pole to gentle tap a swimmer's shoulder to notify them that they have reached the end of the pool. Furthermore, in events for the blind or visually impaired, all swimmers must wear blackened goggles to even the playing field among the athletes, particularly those that have retained partial sight [6]. For athletes prone to hyper or hypothermia, the use of wetsuits or warming/cooling methods may be used as preventative measures during races.

Although competitive swimming does not allow for the use of prosthetics, in the recreational setting, prosthetics serve as a viable option for assisted propulsion in amputees or athletes with congenital limb deficiencies. Generally the prosthetics are similar to those used for ambulation, utilizing a foot that may be covered with a foam material which is both buoyant and water repellent. Usually the foot component has the capabilities to be set in a plantar flexed position to mimic the motions of a normal foot during the kicking cycle of swimming. Newer prosthetics employ a fin or paddle-like structure that sits at the base of the prosthetic instead of a foot. Different prosthetics exist via multiple independent companies, each utilizing different fin-like designs to assist with swimming. The prosthetics allow for decreased energy expenditure through the water with newer, sleeker designs creating increased force with less bulk than older models. Much like prosthetics for ambulation, the suspension must fit comfortably, allowing for a tight hold, decreasing residual limb movement, but not enough to cause serious discomfort. Various sleeve materials exist to help to maximize fit including silicone, urethane, and latex. Furthermore, each of these materials produces for an environment that allows for decreased permeability of water. Other considerations for aquatic-based prosthetics include the use of an exoskeleton as opposed to an endoskeleton, allowing for increase follow of water along the length of the prosthetic during kicking, as well as a water expulsion valve to assist in decreasing water retention and producing a better suspension.

Other Adaptive Water Sports Including Recreational Sports

Adaptive water sports are not limited to just competitive sports, and there are several options available for disabled athletes interested in recreational water sports. Waterskiing, kayaking, canoeing, water polo, and fishing are all just a few examples of sports in which adaptations to equipment or technique may be used to enable participation of a disabled participant. It should be mentioned, however, that although many of these sports are considered recreational, some are gaining traction among athletes enough to be considered for competitive events. One such case in point is that as of the Rio Games in 2016, adaptive canoe will become a Paralympic sport. Modifications available vary depending on the sport and the participant but range from prosthetics designed to hold a fishing pole to modified kneeboards.

Adaptive Canoeing/Kayaking

Adaptations are often unnecessary for paddling equipment for athletes participating in adaptive canoeing, however, if necessary modifications can be made to individual boats to allow for optimal participation. Individuals with only at least one lower extremity can be outfitted with a kayak or canoe that can be controlled via a foot-operated rudder system. For those athletes who have bilateral lower extremity amputations or impairments, the use of upper body paddling strokes can be used to control the direction and speed of the vessel. During competitive paddling outings, as well as recreational, a long, thin canoe known as an outrigger canoes, which is supported by an outrigger or "ama," provides a stable yet sleek boat for the athletes to man [8]. Many canoes used in adaptive paddling can also be rigged with either a double-hull catamaran configuration or a single hull with additional safety outriggers attached to the sides of the canoe to prevent capsizing [8].

Athletes from all five major disability groups, including amputations, spinal cord injury, cerebral palsy, visual impairment, intellectual disability, and "Les Autres," or others, are open to participate on both recreational levels and competitive. In the 2016 Paralympic Games in Rio de Janiero, para-canoeing will be an event offered at the competition for the very first time. The Paralympic competition currently consists of single-person kayaks (K-1) and single-person canoe (V-1) with one male and one female paddler in each of the classifications. The events are 200-m flat water sprint races, performed in lanes that are measured nine meters wide. The K-1 races allow steering rudders and decking and the sprint boats are allowed a maximum length of 520 cm (same as the International Canoe Federation sprint boats) with a greater width of 50 cm at the 10 cm water line compared to kayaks of non-disabled paddlers [8]. In the V-1 races, the canoes consist of rudderless hulls and an outrigger connected by two spars. On either side of the hull is where the outrigger is positioned, or the length of the boat is allowed a maximum 730 cm with a minimum hull weight of 10 kg [8]. Often during the V-1 spring races, athletes use bent shafts or paddles that are angled in order to more efficiently optimize mechanical stroke practices. For athletes participating in the K-1 races, paddles are similar to those used by non-disabled athletes, utilizing scooped and twisted blade designs made of carbon fiber. These specialized paddles allow for good trunk rotation and adequate catch during paddling strokes [8].

For adaptive paddling, seating is one of the most important factors for proper participation and safety during sporting events. Specialized seating in K-1 and V-1 boats provided appropriate support for athletes and with special attention drawn to areas of increased pressure including the buttocks, lower back, torso, and pelvis. Other adaptive seating modifications are specific for different injuries.

Table 21.6 Classifications for adaptive canoeing/kayaking [8]

Legs, trunk, arms (LTA)	Made up of athletes with minimum physical disability including, but not limited to loss of three full fingers on one hand; amputation of tarsal/metatarsal of one foot/loss of strength and range of motion of one limb or two limbs; typically amputee, spinal cord injury S1, cerebral palsy Class 8
Trunk and arms (TA)	Athletes in this group cannot apply continuous and controlled pressure to the footrest due to significant weakness to the lower limbs including athletes with bilateral amputations of the lower extremity around the knee level or significantly weakened lower limbs; typically spinal cord injury athletes consist of complete L3 or incomplete L1; cerebral palsy Class 5
Arms (A)	Athletes with no trunk rotation with movement of arms and shoulders only; includes spinal cord injury of complete T-12, incomplete T-10; cerebral palsy Class 4. These athletes are likely to have poor sitting balance and most likely in need of adaptive seating with lateral and back supports with the higher lesions

For limb-deficient athletes wanting to participate in adaptive paddling, custom socket attachments can be made to hold the residual portion of the amputated limb in place. Athletes with spinal cord injuries will benefit from spray skirts, which are devices donned around the waist or torso and covers the cockpit of the kayak or canoe to keep water out, in order to support and maintain an upright posture during events. Athletes with upper body impairments or amputations require specialized grip adaptations that allow for secure grasping of the paddles as well as are able to be quickly released if the athlete runs into trouble. [8]. Table 21.6 outlines the classifications for the athletes participating in adaptive canoeing and kayaking.

Adaptive Water Skiing

Adaptive waterskiing is another water sport that is open to athletes from all disability groups. Adaptive equipment, including specialized water skis, allows both recreational and competitive participation with many athletes performing a variety of tricks, jumps, and racing in slalom events. Adaptive waterskiing began as early as the 1970s as a recreational pastime for athletes with disabilities. In 1987 the first World Trophy, which was a non-record event, was held in London, England, with 40 participants from seven different countries [9, 10]. As there was a lack of participation in the first competitive event, it was called World Trophy instead of World Championship. Every 2 years since its inception, a global event has been held with increasing interest and participation from athletes all over the world, with the first true World Championship occurring in 1993 [9].

As with other adaptive sports, specialized skis have to be tailored to the individual's needs and disabilities. For athletes with amputations, single leg skis can be utilized or prosthetic ski legs can allow for amputees to control two separate skis and even single skis using one leg and their prosthetic [10]. Those athletes that are unable to stand, like many with spinal cord injuries, can sit-in sit skis which are wider than that of a regular slalom ski. Athletes who suffer from visual impairments use the same equipment as non-disabled people; however, they require another water skier at their side in order to guide them. Sit-down skiers use a singlewide ski with a metal-framed cage attached to it. The skier sits in a canvas sling that can be adjusted either up or down to change the center of balance. Other equipment used by skies include outriggers, which are stand-up water skis that have shortened and secured to a steel frame that mounts between the cage and the ski for stability [9]. For athletes who do not possess good trunk stability, a quad-back can be used to help with balance. For those who are unable to use one of their arms, a Delgar Sling is utilized in which the sling loops around the shoulder of the good arm of the skier, passing behind their back, and hooking directly to the ski rope handle. The Delgar Sling is easily able to be detached from the rope handle in the event of a fall so that the athlete is not dragged behind the boat [9].

Classifications for competitive adaptive water skiing exist that pertain to particular impairments.

In this system, M classification is for quadriplegic, paraplegic, and double leg amputees. Numerical values from 1 to 5 are also used with the M classifications, with the higher the number representing the least amount of physical limitations. A/L is designated for athletes with significant arm and leg impairments/amputations. V represents the athletes who suffer with visual impairments. Similarly to the M classification, the athletes with visual impairments have numerical values that represent level of impairment with the highest number being three, which represents the least amount of visual limitation [9]. Table 21.7 lists the descriptions of the different classes of adaptive water skiing.

An athlete demonstrating correct adaptive waterskiing posture (Photo courtesy of Alan Schleier)

A seated waterskiing setup with cage, outriggers, and rope (Photo courtesy of Alan Schleier)

Table 21.7 Classification for adaptive water skiing [9]

MP1	Athletes have no controlled of trunk movement and majority of their trunk musculature (unsupported) in all planes; minimal or no balance in both forward and sideways directions significantly impaired. Skiers are unable to hold the handle with hands (usually use forearms), lacking full use of their upper extremities. This class generally is made up tetraplegics/ quadriplegics, although skiers with other diagnoses may qualify in this category
MP2	Athletes have little or no controlled trunk movement in all planes with balance in both forward and sideways directions significantly impaired. Skiers rely on their arms to return them to the upright position when unbalanced. There is no active trunk rotation and no use of abdominal muscles. Skiers in this class are generally quadriplegic's with more functional ability and high level paraplegics, although other diagnoses may qualify in this category
MP3	Athletes have some partially controlled trunk movement in the forward direction, but little or no controlled sideways movement. Skiers have upper trunk rotation but poor lower trunk rotation. Skiers in this category are generally mid-level break paraplegics, although skiers with other diagnoses may qualify in this category
MP4	Athletes have good trunk movement in the forward direction to his/her knees and up again without arm support. Skiers have good trunk rotation but limited controlled sideways movement. Skiers in this category are generally lower-level break paraplegics, although skiers with other diagnoses may qualify in this category
MP5	Athletes have normal trunk movement in all directions, able to reach side to side with no limitations and are able to move their hips independently. Skiers in this category are generally amputees who cannot ski standing, skiers with low or incomplete spinal cord injuries with leg control, and skiers with required minimum disability who display controlled sideways or hip movement
A	Athletes with arm amputations
L	Athletes with leg amputations without prosthesis
L/P	Athletes with leg amputations with prosthesis
A/L	Athletes with significant arm and leg impairment including amputations, hemiplegia, cerebral palsy, and other conditions/disabilities in which athletes are able to ski upright for slalom

Table 21.7 (continued)

V1	No light perception in either eye; up to light perception, but inability to recognize the shape of a hand at any distance or in any direction; skiers required to wear "blackout" goggles
V2	From the ability to recognize the shape of a hand to visual acuity of 2/60 and/or visual field of less than 5°
V3	From visual field acuity above 2/60 up to visual acuity of 6/60 and/or visual field of more than 5° and less than 20°. Those athletes who are classified at V2 and V3 always ski in one single category called V2/V3

Common Injuries/Prevention to All Adaptive Water Sports

Common to all aquatic-based activities, drowning prevention is of critical importance in all water sports, even more so in those of adaptive sports. As many adaptive athletes are at an increased risk of drowning secondary to their physical or cognitive impairments, the utmost importance must be placed on specific precautions aimed at limiting the potential for athletes to drown. These include the use of personal flotation devices (PFDs), swim tests, and safety personal onsite during participation. Staff involved in sporting oversight and participation, including coaches, referees, medical staff, as well as teammates need to be wary of the signs of athlete distress. Furthermore, resuscitative measures particular to drowning should be taught to all involved in athletic endeavors, regardless of the sport.

Another safety consideration intrinsic to water sports is the potential for infection. As athletes with a disability carry a higher risk of skin breakdown than non-disabled athletes secondary to prolonged sitting, altered metabolism, increased risk of malnutrition, and altered sensation and awareness of changes to the skin, the potential for skin infection is also increased. This affect is also exacerbated by the fact that disabled athletes may also carry relatively impaired immune systems. Close monitoring of skin should be implemented with regular skin checks, especially in sports such as sailing and rowing that utilize equipment such as wooden oars or ropes. Another risk factor or possible source of infection is the introduction of colostomy bags, catheters, leg bags (should be emptied no more than 3–4 h prior to participation), and other tubes/lines which may be present as part of daily care for disabled athletes. These conduits to the body present their own unique concerns as they present the possibility to not only introduce infection to an athlete but to introduce body fluids into a shared environment. Additionally, bowel and bladder function may be impaired in athletes, and appropriate hygienic measures must be taken to address the possibility of incontinence. Conversely, there is a risk of urinary or fecal retention in certain adaptive athlete populations, creating stagnant bodily waste that could potentiate the risk for further infections.

As mentioned prior in this section, issues regarding skin are of great concern in regard to disabled athletes. Abnormal or impaired sensory interpretation, depending on level and type of injury, make many athletes prone to skin breakdown and insult. The potential of pressure ulcer development in disabled athletes is much higher than it is for non-disabled athletes. Adaptive athletes, especially the SCI population or athletes with decrease tactile sensory input, are at high risk of pressure ulcer formation or worsening of already present insult. The moist environment of water sports as well as the high friction nature on hard-surfaced vessels of sports such as sailing or rowing produces a setting in which skin tears and ulceration can easily occur. Also of concern is skin breakdown at the ends of residual limbs in athletes that wear prosthetics. Prosthetics already create a moist environment as they are warm and sweaty. That coupled with the introduction of water and repetitive movements can irritate the ends or the sides of the residual limbs that have the greatest amount of contact to the prosthetics. This is of great importance that the prosthetics are properly fitted to decrease movement of the residual limb within the socket, thereby reducing the risk of skin degradation.

As athletes often participate in events during the daytime when the sun is most pronounced, the risk for excessive sun exposure is often greatest to athletes who partake in aquatic sporting events. Altered sensation may allow for skin to become severely sun burnt before any notice can be brought to the attention of the participant or the medical staff, increasing risk of infection and morbidity. Careful caution should be taken to ensure that athletes are properly dressed in sun protective clothing, as well as use of sun screens should be implemented often and frequently especially in areas of skin that may be more exposed the sun. Special consideration should be taken with individuals who may have autonomic dysfunction, dysfunction of the thermoregulatory system, or insensate skin as they may be more prone to dangerous fluctuations in body temperature, creating issues with temperature regulation [11]. Such predispositions may lead to overheating in these particular athletes with increased risk of heat intolerance, heat stroke, and dehydration. It is imperative that all adaptive athletes remain well-hydrated throughout events as this may help to prevent dehydration and overheating.

Another complication that must not be overlooked is autonomic dysreflexia (AD) in the SCI population. In athletes with injuries of T6 and above, AD is a phenomenon that occurs when some sort of noxious stimuli causes an imbalanced reflex sympathetic discharge leading to potentially life-threatening high blood pressure [12]. This may be difficult to ascertain in the athletic population as the characteristic signs of AD, including sweating, flushing, and elevated blood pressure, are common side effects of vigorous exercise. Medical staff must be keen to distinguish the difference between normal physiologic responses to exercise in this subset of athletes versus a very dangerous outcome of unregulated sympathetic surges. A high clinical suspicion must be kept for these athletes and in the instance that medical staff feel that the athlete may displaying signs or symptom, the athlete should be prompted to stop participation and immediate medical treatment should commence.

Injuries in Adaptive Swimming

Swimming requires the utilization of both upper and lower extremity strength with varying degrees depending on the type of stroke. However, regardless of stroke, the repetitive motions can predispose athletes to an array of musculoskeletal injuries, more commonly seen in the upper limbs, knees, and spine. Shoulder pain is the most common injury seen in the swimmers, as unlike most other sports, the major generator of propulsive force in swimmers is the upper body. Furthermore, large populations of adaptive swimmers have minimal to no use of their lower extremities, including those with SCI, or have missing limbs, including legs; therefore, more emphasis is placed on the upper extremities to compensate. The biomechanics of the type of swimming stroke, overuse and muscle fatigue, as well as glenohumeral laxity and shoulder instability all play a role in shoulder pain [13]. Other causes of shoulder pain seen in swimmers include shoulder impingement, labral tears, rotator cuff tendinopathies, subluxation, and rotator cuff tears [13, 14]. Less common causes of upper extremity pain in adaptive swimmers include both neurogenic and vascular thoracic outlet syndrome, rib stress fractures, exertional compartment syndrome, sternoclavicular joint subluxation, and os acromiale [13, 15, 16].

Although it is less common than shoulder pain, knee pain is often observed in adaptive swimmers. This, however, is mostly seen in athletes who have some retained mobility of their lower extremities or those with residual limbs spanning across the knee joint. Common among swimmers of all capabilities, knee pain is generally secondary to overuse [17]. Intrinsic knee injuries are generally very rare in swimming as athlete bare little to no impact forces through the joint during the process. Medial compartment synovitis, medial collateral ligament (MCL) strains, pes anserine tendinitis or bursitis, and strain injuries of the hip flexors and adductors, particularly adductor magnus and brevis, are common examples of knee injuries suffered by swimmers [13, 18]. Many of these injuries are stroke dependent and generally are secondary to biomechanical abnormalities or factors causing increased tension and trauma [19]. Rare occurrences of patellofemoral pain have been noted in athletes observed to have patellar instability, subluxation, or maltracking often secondary to quadriceps muscle abnormalities [13].

Despite the lack of high impact in swimming, spine pathologies, albeit rare, do occur. Low back pain is a common complaint among swimmers. It appears to be more prevalent in athletes who perform particular strokes, especially the butterfly and breaststroke. During these strokes, the lower back and lumbar spine tends to hyperextend, loading the posterior portion of the spine [13]. As this hyperextension is repeated, the strain on the spine can lead to spondylosis and spondylolisthesis [20]. Furthermore, athletes who wear finned prosthetics can actually cause excessive hyperextension of the lumbar spine, expediting the degenerating process [13]. Degenerative disk disease or intervertebral disk degeneration is another change to the spine that has been reported in swimmers, with the most common site being the L5–S1 levels. Increased intensity, duration, and distances of swimming have been linked to increase disk disease [13, 20].

Injuries in Adaptive Rowing

As rowing involves continuous repetitive motions, the majority of rowing injuries are secondary to overuse [21]. These injuries are commonly seen in athletes who have increased their intensity and volume of training or competition. Rowers often experience injuries during the fall and winter months as this is the most common times in which competitive rowers train doing long aerobic sets [21]. The most common sites of pain in rowers involve the knee, back, upper extremity, and rib cage.

Rib or thoracic pain is a very common complaint observed in adaptive rowers. Rib fractures, most commonly stress fractures, are one of the most common causes of rib pain [21, 22, 23]. The repetitive motions of rowing, especially of the upper body, can cause muscle fatigue, thereby transferring the overloaded stress to the ribs. Furthermore, many adaptive rowers tend to use their upper body more than their lower often secondary to their impairments. Stress fractures generally affect the fifth through the ninth rib presenting as vague thoracic pain that is insidious in onset [24]. In the instances of traumatic rib fractures, often secondary to injury from oars, the athlete should be assessed immediately as depending on the direction of fracture and severity, a pneumothorax can result from a punctured lung. Other causes of rib pain include costochondritis, intercostals muscle strain, and less commonly costovertebral joint subluxation. These pathologies, much like stress fractures, are all results of overuse.

Knee pain a common pain reported in adaptive rowers who have use of their legs [25]. The main causes of knee pain observed in rowers include patellofemoral pain, chondromalacia patella, and iliotibial band (ITB) friction syndrome. The motion of rowing involves extreme loading through the patellofemoral joint as well significant patella pressure [21]. ITB friction syndrome is secondary to pressure of the ITB against the lateral femoral condyle. As the ITB moves from a position anterior to the femoral condyle during leg extension to a position posterior with knee flexion, there is an increase in pressure and ultimately leading to inflammation and pain [21]. Another cause of lower extremity pain seen in athletes with amputations is residual limb pain, especially while donning a prosthetics. Increased force through the lower extremity prosthetic can cause trauma to the end of residual limb, especially in athletes who aren't properly fitted for the prosthetic. The residual limbs are also at increased risk of skin breakdown and tear as mention previously in this chapter.

In rowers who have use of their legs and arms, another site of injury is the upper extremity. This includes the shoulders and wrists. Often adaptive rowers favor the use of their upper extremities by nature of their disabilities making them prone to injuries. The most common causes of injury to these areas are also overuse injuries, such as muscle strains and stress fractures. Furthermore, injuries to the tendons of the rotator cuff can be injured as the repetitive motions of rowing can put stress through the shoulder joint and cause shearing forces to the tendons. Extensor tenosynovitis of the wrist is another common overuse injury in rowers. It is often secondary to the rotational motions of the wrist as the wrist dorsiflexes when rotating the oar [21].

Lower back pain is often seen in adaptive rowers as well. With each rowing stroke significant loading forces are placed through the lumbar spine. Although the spine is relatively flexible and well suited to resist compression, the amount load generated places increased stress making the intervertebral disc susceptible to injury [21]. Also, the forces of lateral bending and torque during the rowing motion put the spine under tension.

Injuries in Adaptive Sailing

Although little literature exists regarding the prevalence of certain injuries in adaptive sailing, limited studies suggest that injury rates are similar in populations of disabled and non-disabled sailors [26]. One exception to this is rates of upper extremity injuries. A 1999 survey of sailors in the International Foundation for Disabled Sailing World Championship revealed an increased rate of upper extremity injuries in the disabled population. There is a possibility that this may be related to increased rates of rotator cuff disease in manual wheelchair users. Over all, sailing injuries tend to be overuse injuries, and although different surveys have varying results, back injuries tend to be the most common, followed by injuries to the extremities and neck. Weak abdominal muscles often seen in impaired athletes coupled with maneuvers that increase stress through the spine while sailing potentiate the likelihood developing neck and back pain [26]. Furthermore, many actions in sailing are sudden and erratic, placing muscles at increased risk by performing rapid, powerful moves [26]. Upper extremities in adaptive sailors sustain injury because of the increased weight bearing on the upper extremities compared to the lower extremities, especially common in athletes with SCI. Medical providers should be aware of these prevalence rates and encourage teams to execute proper use of equipment and training to minimize injury rates. Additionally, an athlete's level of disability should always be considered in injury prevention and treatment, as the nature of the athlete's disability may predispose them to certain types of injury.

Overview, Conclusions, and External Resources

Water sports offer opportunities for disabled persons to participate in activities, which offer fantastic social, physical, and emotional benefits. Whether casual, club or competitive, the world of adaptive water sports has grown to a point where individuals with a wide range of disability have the opportunity to play and compete in a safe, fun, and rewarding manner. As a medical provider, it is valuable to be aware of these opportunities so that patients may be introduced to water sports and take full advantage of their benefits. Simultaneously, it is critical to be aware of the pertinent sport and patient-specific risks in order to effectively provide medical coverage for adaptive athletes. Sport participation combined with research into regulations, common injuries, and equipment considerations can offer medical providers unique and rewarding opportunity to perform an integral role in these sports.

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22 Ice Sled Hockey (Sledge Hockey Outside the United States)

Ashley D. Zapf and Joan P. Joyce

Introduction

Ice sled hockey was invented at a rehabilitation center in Stockholm, Sweden in the early 1960s by a motivated group of athletes who wanted to continue playing hockey after incurring physical disability [1]. It was first exhibited at the Paralympic Winter Games in Sweden in 1976 and again at the 1988 Paralympics in Innsbruck [2]. It became an official event at the 1994 Lillehammer Paralympics [1]. Since then, the game has quickly become a popular sport for both children and adults.

Presently, ice sled hockey is governed by the International Paralympic Committee (IPC) in coordination with the IPC Ice Hockey Technical Committee [1]. It follows the rules of the International Ice Hockey Federation (IHF) with modifications [1].

Rules

Ice sled hockey is a sport played by males and females who have a lower body physical impairment. It is essentially a seated version of ice hockey for players whose impairments interfere with their ability to stand and skate. The players sit in double-blade sleds and propel with two shortened hockey sticks. The sticks are adapted with metal picks on the end, and players use the spike-end for propulsion and a blade-end for shooting the puck [1].

The structure of ice sled hockey is very similar to that of able-bodied ice hockey. There are six members of each team on the ice during play, one of whom is the goalie. The object of the game is to score on the opponent and to prevent the opponent from scoring. The game is played according to the Official Playing Rules of USA Hockey [1].

Eligibility

According to the IPC, there is only one sport class in ice sled hockey. Athletes must have an impairment in the lower part of their body that would prevent them from competing in able-bodied ice hockey. Thus, ice sled hockey players can exhibit a wide variety of mobility limitations including amputations, spinal cord injuries, spina bifida, and other permanent lower body impairments [2].

Non-disabled players are encouraged to participate in ice sled hockey. Leagues have

A.D. Zapf, MD (✉)
Andrews Institute, Gulf Breeze, FL, USA
e-mail: adzapf@gmail.com; ashley.zapf@bhcpns.org

J.P. Joyce, CTRS, HFS
MedStar National Rehabilitation Network, Washington, DC, USA
e-mail: joan.p.joyce@medstar.net

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_22

developed guidelines for the non-disabled players. However, at the national and international level of Paralympic competition, participation is solely for athletes with impairments.

Equipment

Protective Gear

All ice sled hockey players are required to wear protective equipment consisting of a full face mask helmet and a protective collar or bib [3]. Players are also encouraged to wear protective padding throughout the body, such as shoulder pads, shin guards, and hockey gloves [3].

Sled

Companies specializing in prosthetics and orthotics create custom-made sleds that are designed to fit the body of each individual athlete. The materials used can vary. Cushioning may be added inside the sled to increase comfort and skin protection.

The sleds are generally between 0.6 and 1.2 m long and sit on top on two adjustable steel blades which are 3 mm wide [3]. The sled must be high enough off of the ice in order to allow the puck to pass underneath. The players are strapped into the sleds during play.

Sticks

Ice sled hockey players use two sticks during play. The sticks are equipped with a blade at one end and a pick at the other [3]. As in able-bodied ice hockey, the blade is used for shooting; however, unlike able-bodied ice hockey, the sled hockey player must alternate between the blade and pick in order to provide self-propulsion down the ice. The material of the sticks can vary, but the stick cannot exceed 1 m in length, and the blade cannot exceed 25 cm (35 cm for goalies) [3].

For players unable to propel themselves, a push bar can be added to the sled. During play, a pusher can propel the sled for the player. Rules are in place to limit the pusher's speed and impact on the game.

Medical Management of the Ice Sled Hockey Athlete

The medical management of the ice sled hockey athlete can be quite complex. It is imperative that the staff providing medical coverage be aware of the possible conditions and injuries associated with the sport. This includes identification and treatment of common illnesses, illnesses exclusive to the disabled athlete, and musculoskeletal and neurological injuries unique to the sport and equipment of ice sled hockey.

Infections

In any team setting or sporting event, one has to consider the possibility of common illness or infection affecting the athlete. Although not specific to ice sled hockey, the surveillance study conducted during the London 2012 Paralympic Games investigated the incidence and clinical characteristics of illness in athletes. In this surveillance study, infection was found to account for 40.8% of all illnesses in these athletes [4], highlighting the need for the medical team to thoroughly investigate early signs of infection in this population.

The most common type of infection present during the London 2012 Paralympic Games involved the upper respiratory tract. This type of infection tended to affect those athletes with intellectual impairment, visual impairment, cerebral palsy, and those falling into the Les Autres category. The majority of these infections (70%) were reported on the same day as the appearance of symptoms [4], allowing for prompt diagnosis and treatment.

Those with the greatest number of ailments at the London 2012 Paralympic Games were athletes with spinal cord injuries. In particular, these athletes tended to have issues involving the urinary tract as well as the skin and subcutaneous tissue. Notably, the majority of urinary tract infections were reported 1–2 days after clinical symptoms appeared; there was also an increase in the number of skin and subcutaneous infectious reported after the initial day of symptoms [4]. Medical staff should recognize that athletes may be presenting with infections that have been manifesting for several days and to be mindful about rapid treatment. Additionally, athletes should be encouraged to report symptoms at the first sign of infection, as to avoid complications or spread infection to other athletes.

Dermatologic

Ice sled hockey athletes as a whole have increased risk for skin pressure ulceration. Sled cushioning does not appear to have a significant effect on reducing the risk of pressure ulcers. However, it has been found that knee extension significantly lowers seated pressure, and it is theorized that this may reduce the risk for ulceration in these athletes [5].

Laceration of the hands and trunk appears to be more common in ice sled hockey players [6]. Athletes may have insensate areas of the skin, delaying the recognition of an open wound; additionally, the hands and trunk are covered by equipment that is not sterile. This raises concern over the risk of associated complications, including infection, and thus meticulous inspection and wound care should be administered.

Finally, it is also important to recognize that common dermatologic injuries such as contusions have been found to occur as frequently as they would in able-bodied athletes [6].

Cardiovascular

Athletes with spinal cord injury have been known to be at increased risk for cardiovascular related issues including thermoregulation, autonomic dysreflexia, and orthostatic intolerance.

Thermoregulation has been studied extensively in spinal cord injury. Impaired body temperature regulation affects those with spinal cord lesions at T8 or above, and research has focused primarily on those athletes with high cervical injuries who present with hyperthermia [7]. However, in ice sled hockey, concern over thermoregulation shifts from heat intolerance to hypothermia. The sled hockey athlete plays in cooler conditions, and hypothermia can result from impaired vasomotor control, impaired central temperature regulation, decreased muscle mass below the level of injury, and lack of shiver response below the level of the injury [8].

Autonomic dysreflexia should be monitored for in any ice sled hockey athlete with spinal cord injury at the level of T6 or above. Common signs and symptoms of autonomic dysreflexia include headache, sweating, facial flushing, piloerection, and dilated pupils. These can be hard for medical staff to observe in a sled hockey athlete who is on the ice in full equipment. Patients should be encouraged to immediately report the onset of symptoms as this condition can lead to stroke or death. Hypertension and bradycardia will be present upon exam. The athlete should sit up and have equipment removed, and initial treatment should focus on identifying and removing the inciting noxious stimuli. Common culprits include bladder distention, bowel impaction, and pressure ulcers. It is also worth noting that if an athlete becomes injured while participating in ice sled hockey, the injury itself could serve as a noxious stimulus and induce autonomic dysreflexia.

Medical staff should also monitor for orthostatic hypotension in athletes with spinal cord injuries at T6 and above. Unlike autonomic dysreflexia, these athletes will have hypotension, tachycardia, and complain of light-headedness. Athletes in this state should immediately be placed in a supine position with the lower extremities higher than the head (Trendelenburg). Prevention of orthostatic hypotension may be achieved with equipment such as compression stockings and abdominal binders; however, they should be used with caution in athletes who are prone to autonomic dysreflexia, as they could induce an episode.

Neuromusculoskeletal

The management of musculoskeletal and neurological injuries is an integral part of providing care to the ice sled hockey athlete. Blauwet and Willick have stated, "Common musculoskeletal injuries may have a greater functional consequence in the lives of athletes with disabilities compared with the general athletic population." These injuries not only affect a disabled athlete's ability to participate in sports, but also affect the activities of daily living [9].

Overuse injuries are frequent in sled hockey athletes, just as they are with able-bodied athletes. Able-bodied athletes tend to display overuse injuries of both the upper and lower extremities, with able-bodied ice hockey players having more lower extremity injuries overall compared to the upper extremity [10]. On the other hand, sled hockey athletes have a disproportionate number of upper extremity injuries, specifically those involving the shoulder, elbow, and wrist [6]. This has been attributed to the pulling motion required to propel oneself down the ice, as well as the demand placed on a single upper extremity during shooting in ice sled hockey [6]. Wrist tendonitis is in particular one of the most common overuse injuries cited, thought to be secondary to wrist flexion during shooting [6]. Also present in high frequency is sprain of the shoulder [6], which coincides as one of the most common upper extremity injuries in able-bodied ice hockey players as well [10].

Specific overuse injuries in sled hockey athletes can vary due to differences in athletes' core strength, limb strength, and individual movement patterns. The biomechanics of an athlete with spinal cord injury can be vastly different than that of an athlete with a below knee amputation [6]. The medical team should observe the biomechanics of each individual athlete in order to determine risk for development of an overuse injury while participating in ice sled hockey.

Acute injuries are also common in ice sled hockey. Due to the high impact potential and speed of Paralympic winter sports, injuries such as contusions, fractures, and concussions have been found to be more prevalent [11]. Data collected from 2002 Salt Lake Paralympic Winter Games demonstrated the highest likelihood of injury in athletes participating in ice sled hockey [9]. In particular, body checking during ice sled hockey is believed to lead to more injuries. This has been attributed to the rigid and unforgiving boards at the height of sled hockey players on the ice (compared to the plexiglass at the level of the able-bodied players) [6]. In fact, in able-bodied ice hockey, there is a 29% lower risk of an injury in arenas utilizing flexible boards and glass versus traditional materials [10]. Sled hockey players would likely have a reduced rate of injury if the boards were pliable close to the ice.

While body checking in ice sled hockey can lead to injury of any area of the body, there is great concern regarding the development of concussion. In able-bodied players, the most common cause for concussion is a check to the head [10]. It is theorized that concussion may occur even more frequently in ice sled hockey due to an increased propulsion of the upper body while checking [6].

In able-bodied players, the risk of concussion has been linked to hockey position and body habitus. Concussions occur more commonly in the players in forward positions and, in particular, centers [10, 12]. Also, the majority of concussion cases occur in athletes who are body checked by ice hockey players taller or heavier than themselves [12]. This may have implications for ice sled hockey athletes in terms of torso length, body mass, or even type of disability affecting concussion rates.

In addition to concussion, it is worth noting the head in general is the most commonly injured site in able-bodied ice hockey players, with injuries including facial lacerations and dental trauma [10]. These injuries do occur in ice sled hockey players as well, though they tend to occur less frequently than ailments of the upper extremity [6].

Full facial protection during ice hockey has been shown to reduce the number of facial lacerations as well as reduce the severity of facial, eye, and dental injuries when compared to half or no facial protection [13]. There is less opportunity for severe injuries, such as facial fractures and orbital blowout, to occur. In addition, concussions tend to be less severe with the use of full facial protection, and players return to sport earlier [13]. A mouth guard should be used in addition to full facial protection in order to offer the best defense against dental injury.

There is a continued need to investigate new ways to prevent acute injury in ice sled hockey. At that time of the 2002 Salt Lake Paralympic Winter Games, fractures were noted to be common, accounting for 33% of all injuries [11]. This prompted the IPC Ice Sledge Hockey Technical Committee to recommend lower limb protective gear at all times during play and mandated that all sleds must be of equidistant height from the ice to prevent a sled from riding up and over another at the time of collision [9]. After the introduction of regulation change on protective equipment and sled height, fracture occurrence in ice sled hockey was found to be reduced during the 2006 and 2010 Paralympic Winter Games [11]. The improvement in fracture rate due to central regulation of equipment highlights the need for the continued development of standardizations in ice sled hockey in order to reduce risk of all injury during play.

Discussion

Athletes with lower body impairments are finding the enjoyment of playing ice hockey through the rapidly growing sport of ice sled hockey. The intensity of ice hockey is paralleled, and technical challenges arise as these athletes maintain balance propelling down the ice, shooting, and participating in a full contact sport. Ice sled hockey has become so popular over the past few decades that competition has risen to the international level.

As ice sled hockey continues to grow in popularity, more attention must be paid to the safety of the athletes competing. Even common ailments, such as contusions and lacerations, can have serious consequences for certain sled hockey athletes. The staff providing medical coverage for these athletes should have an understanding of injuries common to ice hockey players as well as conditions specific to disabled athletes. In addition, the players themselves should be educated to report symptoms early in order to receive prompt treatment and expedite return to play.

Finally, it has been shown that regulation of ice sled hockey on a central level can help prevent injuries. Continued modification of rules and equipment will continue to make the sport safe and enjoyable in its ever growing popularity.

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Adaptive Alpine Skiing and Para-snowboarding

23

Brian Joseph Juriga, YouaPa Susan Yang, and Arthur Jason De Luigi

Introduction

Paralympic alpine skiing is a downhill racing adapted for athletes with disabilities. The sport started with disabled veterans with spinal cord injuries and amputees in Germany and Austria during and after World War II and has been expanding ever since [1–7]. It evolved from the 1948 Championship for skiers with impairment in Badgastein, Austria, up to the first Paralympic Winter Games in Ornskoldsvik, Sweden, in the year 1976. The only two events in alpine skiing at that time were slalom (which is from a Norwegian word meaning sloppy path) and giant slalom. Not until in 1980 in Geilo, Norway, did downhill get added to Paralympic alpine skiing as a demonstration sport. It was officially an event at the 1984 Winter Paralympics in Innsbruck, Austria. Furthermore, in 1984 sit skiing was added as a demonstration sport. Super G was not added until 1994 at Lillehammer, Norway, even though it was developed in the 1980s. In 1998 sit skiing and visually impaired skiing were added as full medal events in Nagano, Japan. In 2010 super combined was added for the Paralympic Winter Games in Whistler Creekside, Canada. Finally in 2014 para-snowboard cross was added to the Paralympic Winter Games at Rosa Khator Extreme Park in Sochi, Russia (Fig. 23.1a, b).

Para-alpine skiing has six different disciplines as follows [1–7]: downhill, super G, slalom, giant slalom, super combined, and snowboard. The rules for each discipline are different based on various rules adapted for skiers with disabilities from the International Ski Federation. Even skiing with these various disciplines and their disabilities, athletes can still reach speeds of 62–72 mph. Before all disciplines, there is a 1–2 h time of inspection for all the athletes with their coaches of the course to make sure all the equipment is correct.

Downhill is a timed speed-based discipline in which athletes ski down a steep course involving many turns and jumps finishing 450 m (1480 ft.) to 800 m (2600 ft.) lower than when they started. Downhill discipline has the skiers navigating through the least amount of gates, but they are going the fastest and down the steepest terrain with turns and jumps. If an athlete misses one gate, they are disqualified. The winner is the one with the fastest time based in one run. Downhill women's skis must be at least 200 cm (79 in.) long with a tolerance of 1 cm (0.39 in.), a minimum radius of 45 m (148 ft.), a profile radius of 6 mm (2.6 in.), and curved ski poles. The only difference for men is that the ski length must be at least 205 cm (81 in.). Before all downhill events, at least one practice run is required.

Super G (super giant slalom) discipline is more technical than downhill but not as technical as some of the other disciplines (Fig. 23.2). It is a

B.J. Juriga, DO, FAOASM (✉)
Sports Medicine Lake Health System,
29804 Lakeshore Blvd., Willowick, OH 44095, USA
e-mail: bjuriga@msn.com

Y.S. Yang, MD • A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA
e-mail: ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_23

Fig. 23.1 (**a**) Photograph courtesy of Brian J. Juriga. (**b**) Photograph courtesy of Brian J. Juriga

Fig. 23.2 Photograph courtesy of Brian J. Juriga (super G)

little slower than the downhill but faster than the slalom or giant slalom. It usually is not as vertical as the downhill and usually has a drop of 400 m (1300 ft.) to 600 m (2000 ft.) from start to finish. It is longer than the giant slalom and the slalom but shorter than the downhill. It is considered a speed event where athletes ski between alternating red and blue gates that are 25 m (82 ft.) apart with a minimum of 30 directional changes. Women need to clear at least 30 gates and men

Fig. 23.3 Photograph courtesy of YouaPa Yang (giant slalom)

Fig. 23.4 Photograph courtesy of YouaPa Yang (slalom)

need to clear at least 35 gates. All the parameters for the skis and poles for super G is the same as downhill for men and women, except that the ski minimum radius is 33 m (108 ft.) and a profile radius of 65 mm (2.6 in.).

Giant slalom involves two runs down a course that is straighter and shorter than slalom but with fewer gates and alternating smoother and wider turns than the downhill (Fig. 23.3). It is a lot less vertical from top to bottom ranging from 300 m (980 ft.) to 400 m (1300 ft.). It is considered one of the more technical disciplines. The winner is based on the combined times of both runs. The starting order for the second run always starts with the slowest of the top 15 or 30 going first and the fastest with the top 15 or 30 going at number 15 or number 30. Skiers finishing outside of the top 15 or 30 then have to ski in order based on their times from the first run. At any time after the first run of giant slalom, the bottom 20% of the finishers can be eliminated from competition based on the discretion of the judges. Additionally, ski length is 155 cm (61 in.) for women and 165 cm (65 in.) for men and they use straight poles.

Slalom is the most technical discipline of them all (Fig. 23.4). It involves two runs each going down a different course set by a different

Fig. 23.5 Photograph courtesy of YouaPa Yang (super combined)

set of people. There are 40–60 gates for women and 55–75 gates for men, and if a skier misses a gate in either run, they are disqualified. It has the least vertical drop from 140 m (460 ft.) to 220 m (720 ft.) on a bulletproof iced course. Both men and women's specifics for their equipment are a minimum of 155 cm (61 in.) for women and 165 cm (65 in.) for men in length. Additionally, straight poles are used and the skiers have padding on their shins, forearms, hands, and back. Similar to giant slalom, after the first run, the bottom 20% of the finishers can be eliminated per the judge's discretion. Also, the starting lineup for the second run always starts with the slowest of the top 15 or 30 going first and the fastest with the top 15 or 30 going out at number 15 or 30. All skiers finishing outside of the top 15 or 30 will then ski in order based on their times from the first run.

Super combined is a discipline that combines either slalom and super G or downhill and slalom (Fig. 23.5). During this discipline the athletes do one run on the downhill or super G and two runs on the slalom. The times for the races are combined with the fastest of the combined times winning the race.

Snowboarding is the final discipline for para-alpine skiing (Fig. 23.6). The course from top to bottom drops between 100 m (330 ft.) and 240 m (790 ft.) for a distance of 400 m (1300 ft.) to 900 m (3000 ft.) for both men and women. It is a course made up of berms, jumps, rollers, and

Fig. 23.6 Photograph courtesy of Brian J. Juriga (snowboarding)

other man-made obstacles that need to be navigated through alternating gates. Unlike snowboard cross in able-bodied athletes where heats of four athletes at a time go at once, in the para-athletes, they go one at a time. They have three runs on the course and their two best runs are combined. Para-snowboarding at this time is only open for standing athletes.

Overall six different disability groups for men and women are in the Paralympics as follows [3]: amputee, cerebral palsy/brain injury/stroke, blindness/visual impairment, wheelchair users/spinal cord injuries, intellectual disability, and Les Autres (a group which includes all those that do not fit into any of the previous groups). The amputee athlete groups are categorized into partial or total loss of at least one limb, such as upper extremity or lower extremity and also into single loss or multiple loss of limb. The cerebral palsy group athletes are considered any athletes with nonprogressive brain damage such as cerebral palsy, traumatic brain injury (TBI), stroke, or any similar disability affecting muscle control, balance, and/or coordination. The intellectual disability athletes are those with a significant impairment in intellectual functioning and limitations in adaptive behavior. The spinal cord injury group consists of any disabilities which require an athlete to use a wheelchair and/or a sit ski for competition because of a spinal cord injury or injuries. The visually impaired group is broken up into partial vision, legally blind, and total blindness. The final group termed Les Autres (aka French for “the others”) includes all athletes with a physical disability that does not fall under one of the other five categories. Examples of this include dwarfism, multiple sclerosis, and congenital deformities of the limbs such as that caused by thalidomide.

Classification is very important in para-alpine skiing because it has a significant impact on the success of an athlete in competition. Classification is an evidence-based system with a stated purpose to promote participation in sport by people with disabilities by minimizing the impact on the impairment on the outcome of the competition [1–7]. The method used in assigning the classification goal is to classify the impairment not the athlete. The overall goal of classification is designed to ensure fair competition between alpine skiers with different types of disabilities. The classification is by the International Classification of Functioning, Disability and Health. Additionally, classification helps in reducing the sports likelihood of one-sided competition and promotes participation. The classification system is internationally accepted, and in the Paralympics, it is based on the degree of function presented by the disability rather than medical diagnosis [1–7]. Therefore, a complete L2 spinal cord injury can compete against a bilateral above-knee amputee fairly. The classes are determined by a variety of processes that include but are not limited to physical and technical assessment and observation in and out of competition. Over all the classifications are grouped into three general disability groups as follows: standing, sitting, and blind [7].

There are individuals that specialize in sports certification and the process of classification and are called classifiers. Classification is not a one-time thing. It is an ongoing process through an athlete’s career, where their allocated class can consistently be reviewed throughout their career. The classifications are grouped into three general disability types: standing, sitting, and visually impaired [8]. They are then further classified based on medical assessment and their body position when they ski, with the exception of visually impaired skiers who are evaluated purely on medical assessment. Skiers with physical impairment who compete standing are classified from LW1 to LW9 (LW is an abbreviation for “Locomotor Winter”) (Fig. 23.7). Athletes with LW1–LW4 classifications have lower limb impairment and LW5–LW8 classifications are for upper limb impairments (Fig. 23.8). LW9 classification is for athletes with combined arm and leg impairments (Fig. 23.9a–c). The final three LW classifications (LW10, LW11, and LW12) are for skiers with a physical impairment affecting their legs and require them to compete

Fig. 23.7 Photograph courtesy of YouaPa Yang (lower limb impairment)

Fig. 23.8 Photograph courtesy of Brian J. Juriga (upper limb impairment)

using a sit ski and are allocated different classes depending on their sitting balance (Fig. 23.10a, b). Athletes with a visual impairment ski with a guide. The guide skis in front of the athlete and gives verbal directions to the athlete through a radio-frequency headset and microphone (Fig. 23.11). There are three different classifications based off the amount of visual impairment. The classifications are B1, B2, and B3 (B being an abbreviation for “blind”). Finally, snowboarding athletes are all classified as SB-LL (SB is an abbreviation for “snowboard,” and LL is an abbreviation for “lower limb”) (Fig. 23.12). All of these athletes have leg impairments such as amputations above the ankle, stiffness of the ankle or knee joint, or muscle weakness. These athletes with amputations use prostheses during the races (Fig. 23.13a, b).

Alpine classifications are as follows [2, 3, 8–11]:

- *Skiers with leg impairments standing classes* (Fig. 23.14a, b):
- *LW1*: Double-leg above-knee amputation, significant muscle weakness in both legs, moderate to severe cerebral palsy, incomplete paraplegia, or incomplete equivalent impairment. This class is for athletes with impairments that affect both legs. Athletes can use one or two skies and either poles or outriggers.

Fig. 23.9 (**a**) Photograph courtesy of YouaPa Yang (upper and lower limb impairment). (**b**) Photograph courtesy of YouaPa Yang (upper and lower limb impairment) (**c**) Photograph courtesy of Brian J. Juriga (upper and lower limb impairment)

Fig. 23.10 (**a**) Photograph courtesy of YouaPa Yang (sit skiers). (**b**) Photograph courtesy of Brian J. Juriga (sit skier)

Fig. 23.11 Photograph courtesy of YouaPa Yang (visually impaired)

Fig. 23.12 Photograph courtesy of Brian J. Juriga (snowboarding)

Fig. 23.13 (**a**) Photograph courtesy of Brian J. Juriga (prosthesis). (**b**) Photograph courtesy of Brian J. Juriga (prosthesis)

- *LW2*: Single-leg above-knee amputation or one with severe functional impairment like an impaired leg since birth. Athletes ski with one ski and outriggers.
- *LW3*: Double below-knee amputees, moderate to severe functional impairment in both legs, incomplete paraplegia, spina bifida, mild cerebral palsy (CP5 and CP6), mild coordination problems, muscle weakness in both legs, and/or equivalent. Athletes ski with two skis and poles or outriggers.
- *LW4*: Single-leg below-knee amputation, functional impairment in one leg, and weakness in one leg but with less activity limitation than LW2. Athletes use two skis and two poles.
- *Skiers with arm impairments standing classes* (Fig. 23.15a, b):
- *LW5/7-1*: Double-arm amputation above the elbow or bilateral arm with limited muscle power and/or coordination problems. Athletes use two skis and no poles.
- *LW5/7-2*: Double-arm amputation, one above and one below the elbow. Athletes use two skis and no poles.
- *LW5/7-3*: Double-arm amputation below the elbow. Athletes use two skis and no poles.
- *LW6/8-1*: Single-arm amputation above the elbow or impairment of one arm such as loss of one hand or arm. Athletes use two skis and one pole only.
- *LW6/8-2*: Single-arm amputation below the elbow or impairment of one arm such as loss of one hand or arm. Athletes use two skis and one pole only.
- *LW9-1*: Amputation or loss of one arm and one leg above the knee or equivalent impairment of one arm and one leg above the knee or

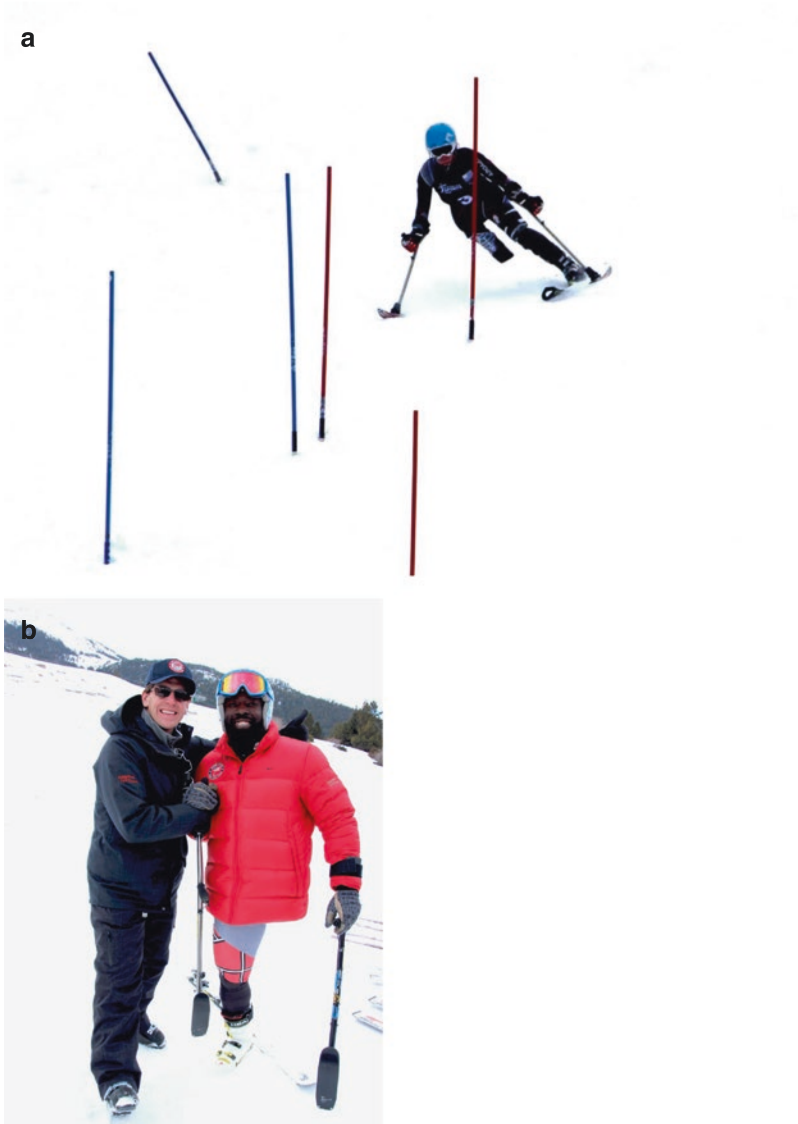

Fig. 23.14 (**a**) Photograph courtesy of YouaPa Yang (lower leg impairment classes). (**b**) Photograph courtesy of YouaPa Yang (lower leg impairment classes)

the same on opposite sides of the body. Some skiers in this class have coordination problems such as spine stability or some loss of control over one side of their body. Athletes use one or two skis and one pole or outrigger.

- *LW9-2*: Amputation or loss of one arm and one leg below the knee or equivalent impairment of one arm and one leg below the knee on the same side or opposite sides of the body. Some skiers in this class have coordination problems such as spine stability or some loss of control over one side of their body. Athletes use one or two skis and one pole or outrigger.
- *Sport classes LW10–12 sit skiers (aka monoskiers)* (Fig. 23.16a–c):

Fig. 23.15 (**a**) Photograph courtesy of Brian J. Juriga (arm impairment standing classes). (**b**) Photograph courtesy of Brian J. Juriga (arm impairment standing classes)

All sit skiers have various impairments affecting their legs. They are all allocated into different sport classes depending on their level of sitting balance, which is very important for acceleration and balancing during the races.

LW10-1: Athletes have paraplegia with very poor active sitting balance (with no upper abdominal function) and limited lower back muscles. Therefore, they have no functional sitting balance. Athletes suffer from spinal cord injury at levels of T7 through T10 (just below the chest) or spina bifida. They rely on their arms to maneuver the sit ski.

LW10-2: Athletes have paraplegia with poor active sitting balance (with some upper abdominal function) and limited lower back muscles. Therefore, they have no functional sitting balance. Athletes suffer from spinal cord injuries at levels T7 through T10 (just below the chest) or spina bifida. They rely on their arms to maneuver the sit skies.

LW11: Athletes have paraplegia with fair to moderate functional active sitting balance and palpable abdominal contractions and some lower back muscles. This allows them to have good ability in their upper trunk but have very limited control in their lower spinal cords, trunk, and hips. These athletes have spinal cord injury at levels T11-L1 (at and around the waist).

LW12-1: Athletes with low level paraplegia with normal or slightly decreased trunk function and some leg function. Athletes have good sitting balance. Skiers with leg impairments in sport classes LW1-4 often fit this sport class. Therefore, they can choose if they want to ski sitting or standing in the beginning of their career.

LW12-2: Athletes with low-level paraplegia with normal or slightly decreased trunk function but have double-leg amputations above the knees.

- *Visually impaired sport classes B1–B3* (Fig. 23.17a–e):
- *B1*: These athletes are either totally blind or do not have the ability to perceive light in either eye and are also unable to recognize the shape of a hand at any distance. They cannot recognize the very large letter E (15 × 15 cm

Fig. 23.16 (**a**) Photograph courtesy of YouaPa Yang (monoskier classes). (**b**) Photograph courtesy of Brian J. Juriga (monoskier classes). (c) Photograph courtesy of YouaPa Yang (monoskier classes)

Fig. 23.17 (**a**) Photograph courtesy of Brian J. Juriga (visual impairment classes). (**b**) Photograph courtesy of Brian J. Juriga (visual impairment classes). (**c**) Photograph courtesy of Brian J. Juriga (visual impairment classes). (**d**) Photograph courtesy of Brian J. Juriga (visual impairment classes). (**e**) Photograph courtesy of Brian J. Juriga (visual impairment classes)

in size) at the top of the Snellen eye chart from just 25 cm away. During the race, these athletes are required to wear eye shades.

- *B2*: The athletes in this class have a slightly higher visual acuity than the athletes in the B1 class. They are able to recognize the shape of a hand and have a standard vision of <2/60 and/or visual field of less than 5°. They are unable to recognize the big E (15 × 15 cm in size) at the top of the Snellen eye chart from a distance of 4 m.
- *B3*: The athletes in this class have the least severe visual impairment of the three alpine skiing classifications. Their standard vision is between 2/60 and 6/60 (20/200 Snellen) and have a restricted field of vision greater than 5° but less than 20°.
- In the IPC Alpine Skiing visually impaired classification, all athletes require a guide. The athlete's guide is obviously a great athlete and skier since he/she has to ski in front of the Paralympic xathlete and verbally gives turn-by-turn directions and other instructions to the athlete skiing down behind them.
- *Para-snowboarding classification* (Fig. 23.18):
- *SB-LL*: Athletes with a physical impairment affecting one or both legs who competes standing.
- *SB-UL*: Athletes with a physical impairment affecting one or both arms who competes standing.
- *Adaptive alpine (downhill) skiing equipment* [3, 7, 12, 13]:

  Currently there are many different options for adaptive skiing equipment for those with limb deficiencies. These athletes have the option to ski either sitting or standing. There are different varieties of equipment for these athletes based on whether they have an upper or lower extremity limb deficiency (Fig. 23.19a, b). Most of the time, upper extremity amputees or deficiency athletes will typically ski standing up with or without adaptive equipment. If the athlete does decide to use something, it is usually a prosthesis with a hand to hold a ski pole or a specialty made terminal device with a ski pole attached to its end (Fig. 23.20). An example of this is an outrigger which is a modified forearm crutch called a Lofstrand attached to ski tips (Fig. 23.21). These ski tips are usually modified with a special locking and release system. In this way, they can be locked into a fixed position such as a flat position for skiing or flipped up to a pointed position for gripping the snow to push and/or pull them forward and backward, essentially acting as a walking crutch. These types of outriggers are called a flip-ski [12].

Fig. 23.18 Photograph courtesy of Brian J. Juriga (para-snowboarding classes)

Fig. 23.19 (**a**) Photograph courtesy of YouaPa Yang (downhill skiing equipment). (**b**) Photograph courtesy of YouaPa Yang (lower extremity limb deficiency)

Athletes with lower extremity amputees or deficiencies also have multiple prosthetic options. The differences in these athletes are that their deficiencies are either transtibial or transfemoral. They have the option of skiing either sitting or standing. Usually the athletes with a single lower extremity deficiency ski standing with or without a prosthesis (Fig. 23.22a, b). An athlete with a unilateral transfemoral limb deficiency will usually ski with a single ski with bilateral outriggers (Fig. 23.23). Most sit skiers are athletes with bilateral lower extremity limb deficiencies or amputees that are most commonly at the transfemoral level (Fig. 23.24). Lower extremity skiing prosthetics have a major difference for an athlete skiing with a transfemoral deficiency and using a prosthesis versus a transtibial deficiency prosthesis, that is, the socket and the addition of a knee unit. The knees typically involve a single axis to start and can be advanced to a more dynamic option as they advance in skill. In all types of prosthetic knees, the center of gravity should always be set in front of the ankle. The anterior socket brim where the athlete places their extremity into should be 1 in. behind the prosthetic toe. The prosthetic knee length is based on individual needs but usually is reduced in size to create a flexed lower limb in an athletic stance. Usually additional modifications are made for foot dorsiflexion if warranted with additional external knee support. The advanced prosthetic users even have prosthetics that can eliminate the boot altogether. This is by molding the plantar surface of the ski foot after the boot sole and then attached directly to the binding, thereby, eliminating the boot altogether. This advanced option alone eliminates excessive weight and, more importantly, enhances energy transfer to make the ski more effective in its performance. Another way to ski with a lower extremity prosthesis is to use a traditional foot as the terminal

Fig. 23.20 Photograph courtesy of Brian J. Juriga (prosthesis)

Fig. 23.21 Photograph courtesy of Brian J. Juriga (outrigger)

Fig. 23.22 (**a**) Photograph courtesy of YouaPa Yang (lower leg deficiency with prosthesis). (**b**) Photograph courtesy of YouaPa Yang (lower leg deficiency without prosthesis)

devices form so the limb-deficient athlete can pop the ski off and continue to ambulate normally with the prosthesis in the ski boot. This traditional foot comes in two different forms as follows: a solid ankle cushioned heel (SACH) foot or a dynamic response foot, which is usually designed to be used in conjunction with an adjustable multiflex ankle (Fig. 23.25). This gives a more natural ankle motion, as well as comfort and stability on uneven ground. No matter which type of the aforementioned foot used, either one requires a 1 in. heel wedge providing a forward cantor when the prosthesis is in the ski boot [12].

Depending on the disability, other terms to know when working with alpine skiing athletes with limb deficiencies are as follows. Three-track skiing is a stand-up skier using both one ski and two handheld outriggers or two skis and one outrigger (Fig. 23.26). Outriggers are there to help the limb-deficient athlete compensate for stability and also help them initiate their turns. The three-track disability group usually includes, but is not limited to, amputees, post-polio, and some congenital birth defects. When learning how to ski with their deficiencies, instructors usually use two forms of teaching, if needed,

Fig. 23.23 Photograph courtesy of Brian J. Juriga (unilateral transfemoral limb deficiency)

depending on the circumstances. Two-track skiing with a tether is used to give extra help to somebody learning to steer their skis. This tether system is connected to the front of the ski tips in conjunction with a ski bra. This system allows an instructor to make the turn for the skier so they can learn the feel of the turn until they are able to progress to making turns themselves. This tether system is not limited to usage in limb-deficient athletes or skiers. It is also used when teaching children how to ski. A four-track skiing system is used by athletes that have leg strength and/or stability issues, as well as whole-body disabilities affecting all or multiple joints and muscles. Examples of this include cerebral palsy, multiple sclerosis, post-polio, spinal cord injury, stroke, muscular dystrophy, spina bifida, and some limb-deficient athletes. This is another form of stand-up skiing with or without a tether. Usually a tether is used when learning how to ski with their disability or those who just want to experience skiing and are able to stand. However, those that compete at a higher level usually use

Fig. 23.24 Photograph courtesy of Brian J. Juriga (bilateral lower limb deficiency)

Fig. 23.25 Photograph courtesy of Brian J. Juriga (SACH foot)

two skis with two handheld outriggers for balance providing four points of contact with the snow. Additionally, sometimes a rope or cord is placed between the tips of the two skis to help athletes keep skis together which help for control purposes. This is especially helpful for the

Fig. 23.26 Photograph courtesy of YouaPa Yang (three-track skiing)

Fig. 23.27 Photograph courtesy of YouaPa Yang (spina bifida)

athletes who are very weak with lower extremity muscles, such as in the case of some with spina bifida [12] (Fig. 23.27).

Sit skis, otherwise known as single monoskis or double bi-skis, are usually used by athletes with bilateral lower limb functional impairments such as bilateral lower extremity amputees, spina bifida, and spinal cord injuries, specifically as follows (Fig. 23.28):

1. *Monoski disability groups*: brain trauma, double amputee, post-polio, muscular dystrophy, cerebral palsy, spinal cord injuries below level of T4, multiple sclerosis, and spina bifida
2. *Bi-ski disability groups*: cerebral palsy, multiple sclerosis, muscular dystrophy, amputees, spinal cord injuries, spina bifida, severe epilepsy, and severe balance impairment

Fig. 23.28 Photograph courtesy of YouaPa Yang (sit skier)

Sit skis consist of a seating system that is either an off-the-shelf seat or an individualized custom-molded seat. The custom-molded seat is typically preferred. It is aligned and mounted on a frame with a shock absorber and suspension below their seating system which allows it to absorb impact on uneven terrain and to assist with turning. Additionally, the seating system has a removable hard external shell to protect the athlete from injury [12].

A monoski interfaces with a single ordinary alpine ski via a metal or plastic block in the shape of a boot sole that clicks into the binding of the ski (Fig. 23.29a, b). This complex is also known as a "ski foot." Monoski in general is designed for independent skiers that are more advanced with good upper body strength and balance [12].

A bi-ski is made up of two specialty shaped skies that can be skied independently. They are attached via a pivot with additional bindings attached to it. The apparatus is then attached to the ski frame. In general, monoskis are more commonly used by more advanced skiers, whereas bi-skis are most commonly used by athletes with more impaired balance and beginners. They are also skied with the assistance of an instructor using a tether. Both the monoskier and the bi-skier use outriggers for stability, turning, and as a modified forearm crutch, the Lofstrand as mentioned earlier. The customized sit ski's frame allows for both rearward and downward movement of the top part of the frame in relation to the lower portion of the frame in loaded conditions. There is also a pivotally attached link arm to the lower frame that allows a forward end and rear end to be attached to a ski or skis. Additionally, a footrest can be modified to be attached to the forward end of the frames' lower portion for non-amputee-seated skiers [12].

The sit ski shock absorber/suspension functions twofold. First, it is to help absorb some of the impact from the terrain for the athlete, and second, it is to minimize transfer of vibration and force between the lower and upper frame. This shock absorber/suspension can be modified by the athlete via a piston and spring depending on what type of discipline they are competing and how much compression is needed. Its overall goal is to keep the athletes sit ski on the snow as much as possible, while they are skiing by compressing to absorb the impact on the front of the ski and then uncompressing appropriately to rebound or extend off the terrain with the middle to back of the ski. With regard to terminology, slow dampening means the same as tightening the adjustment, otherwise compressing the piston and spring. In contrast to fast dampening which is the same as loosening the

Fig. 23.29 (**a**) Photograph courtesy of Brian J. Juriga (monoski). (**b**) Photograph courtesy of YouaPa Yang (monoski)

adjustment, otherwise uncompressing the piston and spring. Besides the previously mentioned ways to adjust the shock absorber/suspension system, the athlete also has to function in droop and sag. Droop is the rebounding or off-loading of the shock absorber/suspension system when the weight of the skier is removed. Sag is the comparative compression of the suspension at rest while it is off loaded versus with the weight of the skier on it. So how does all this make sense by watching a skier take a jump when you observe the weightlessness of midair flight that allows the suspension to completely extend? Apparently, the most optional sag ranges between 20 and 30% of the total shock being absorbed. Therefore, when the athlete adjusts their spring preload, they would use the length of the exposed shaft without the weight on the suspension. Then determine 20–30% of that length for adjustment. Tightening the spring will decrease sag and loosening the spring will increase the sag [12].

There are a couple more important factors that need to be considered and adjusted on the shock absorber/suspension system as well. High-speed rebound (HSR) dampening is what controls the rebound speed of the shock on uneven terrain at high speeds. If the shock absorber/suspension system feels loose or soft, by tightening the HSR, one will slow down the rebound speed. On the other hand, loosening the HSR will increase the rebound speed for when the suspension feels hard. The importance of the HSR is that it allows the shock absorber/suspension system to recover. If the HSR does not recover fast enough, it will result in what is termed a packed shock. This means that the shock absorber/suspension is not recovering fast enough to handle uneven terrain, and there is an increased risk of a wreck. Low-speed rebound (LSR) dampening controls the rebound shock speed in low-energy situations such as going on smooth terrain or small moguls. If the shock absorber/suspension system is not rebounding fast enough to absorb successive uneven terrain or moguls, then LSR can be loosened to decrease the resistance and to increase the rebound speed [12].

High-speed compression (HSC) dampening's main job is to control the compression speed of the shock on uneven terrain at high speed. Tightening the HSC slows the compression speed and the suspension giving more resistance. On the flip-side, loosening the HSC provides less resistance and increases compression speed. HSC's importance is seen in high-impact landings as it affects the bottoming resistance of the shock. Low-speed compression (LSC) dampening controls the compression speed of the shock in low-energy situations such as turning in smooth terrain and light uneven terrain like smaller moguls. Therefore, if compression resistance is too low, then the suspension may compress too much to the point of bottoming out during regular turns on smooth terrain. Additionally, turning down the LSC will allow the athletes ski to engage more quickly at the top of their turn. However, if the athlete feels their ride is too harsh over relatively smooth terrain or the ski is engaging into a turn too quickly, then he/she can decrease the compression resistance by loosening the LSC [12].

The last factor to consider in these highly adaptive sit skis are the types of frames. These frames vary for disability level, type of skiing, and alignment. Typically all frames weigh between 30 and 50 lbs. There are a plethora of different types of monoski frames; however, there are five most common ones as follows:

1. *Bramble frame*: American design made up of stainless steel and aluminum. The skier's position is in a reclined position. The Bramble uses a dual swing suspension also with a shock-absorbing system [12] (Fig. 23.30).

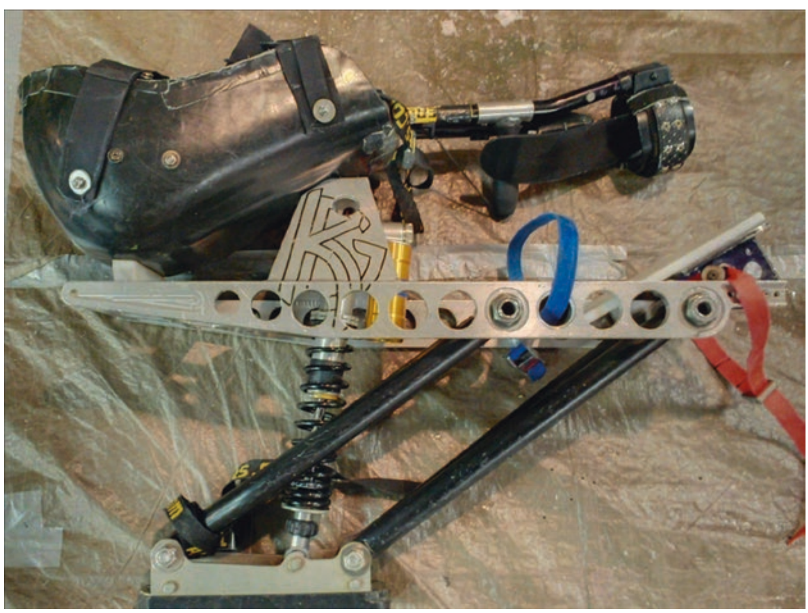

Fig. 23.30 Photograph courtesy of Arthur Jason De Luigi (Bramble frame)

2. *Nissin frame*: Japanese design made up of aircraft grade aluminum which is lighter weight. The skier's position is more upright in an athletic stance alignment. The Nissin uses a pivot suspension that functions like a toe wound if it was compressed with a shock-absorbing system [12] (Fig. 23.31).

Fig. 23.31 Photograph courtesy of Arthur Jason De Luigi (Nissin frame)

3. *Tessier frame*: French design made of stainless steel known for its agility and speed. Tessier's shock absorber/suspension system can be modified by using either a Fournales FT which is a pneumatic shock absorber with a hydraulic damper or an Ohlins shock absorber with a viscous oil under gas pressure allowing the oil and gas to be kept apart by a floating piston. The Tessier also uses a linkage suspension [12].
4. *Praschberger frame*: Austrian design that is similar to the Tessier. It is made of stainless steel and is also used for agility and speed but is also known as a good frame for slalom. The Praschberger uses a linkage type of suspension also similar to the Tessier with a shock-absorbing system [12] (Fig. 23.32).
5. *Hands on Concept (HOC) frame*: A newer American-designed frame which is a hybrid of all these earlier frames. It is made up of mainly aluminum with some stainless steel. The athlete is set up in more of an athletic upright stance position like the Nissin, and it uses a lower shock absorber/suspension system like the Nissin [12] (Fig. 23.33).

Additionally, there is a cart ski design as an option for athletes with greater impairments such as quadriplegia from a cervical spine

Fig. 23.32 Photograph courtesy of Brian J. Juriga (Praschberger frame)

Fig. 23.33 Photograph courtesy of Arthur Jason De Luigi (HOC frame)

injury. Finally, the sit ski is completed with a ski on skis and binding(s). The binding usually does not change; however, the ski varies between events based on specific requirements for that discipline [12].

All frames require individualized settings for their bindings to connect their buckets to their skis. These individualized settings are based on the athlete's ski level. Most of the time, the styles are dependent on the ski brand. For example, Marker 30 fits Marker and Head Skis, whereas Salomon 920 fits Salomon and Atomic skis. These are just some of the many combinations used by these athletes [12].

There is a misnomer in Paralympic or any type of adaptive skiing that there are all kinds of different medical conditions and injuries to be worried about. Medical conditions in all of the adaptive sports are similar to both able-bodied athletes and other standing adaptive athletes, no matter if they are using a wheelchair or other sitting equipment to do their sport. The main difference is the athlete's injury pattern usually from upper extremity overuse or traumatic injuries is different. For example, upper extremity injuries are more common in spinal cord-impaired athletes using sitting equipment to compete. This is in contrast to lower extremity injuries, which are more common in ambulatory athletes that are impaired (i.e., single-leg amputee skiing) and nonimpaired skiers.

Overall, the injury rate in Winter Games is 10% for the amount of athletes competing from alpine skiing and sled hockey; however, 77% of all these injuries are usually due to a secondary acute traumatic event [1, 14–17]. This ranges from huge massive wrecks to minor wrecks to simply landing on an outrigger. Currently, lower limb fractures and ligament knee injuries are the most common injuries in standing alpine skiing. Athletes in the seated alpine skiing classes usually have more upper limb injuries overall. However, concussions and other head injuries, as well as neck injuries, are on a rise approaching the aforementioned injuries in both standing and seated athletes. In general, in winter alpine sports, contusion, fractures, and concussions overall are more prevalent because of the impact potential and speed.

Medical care of the Paralympic alpine athlete is very multifunctional including all but not limited to the following [3]: pre-existing trauma, pre-existing medical conditions, musculoskeletal, neurologic, vascular, cardiac, dermatologic, infections, endocrine, gastrointestinal, genitourinary, psychological, and environmental. What this means is that a medical provider needs to be very familiar with the medical history of all the athletes he/she is taking care of when traveling with the team. It is important to have access to their medical cards and files and become familiar with them.

Previous pre-existing trauma situations to consider when taking care of your athletes are the following: presence of hardware (screws, plates, and/or pins), history of fractures (as previous skeletal injuries may appear or new X-rays), history of splenectomy, history of nephrectomy, and history of prior traumatic brain injury. Previous pre-existing medical conditions include those such as multiple sclerosis, cerebral palsy, muscular dystrophy, spina bifida, diabetes, history of clots or pulmonary embolisms, history of autonomic dysreflexia, UTI's (almost all sit skiers), altitude illness, and impaired thermoregulation issues.

Most of the time, a medical provider needs to combine the neurovascular and musculoskeletal systems into just one neuromusculoskeletal system.

The reason for this is because with most of these athletes that get injured musculoskeletally, they may not be able to feel their injuries as much due to their impairments. Therefore, it is important to distinguish insensate athletes that do not have normal sensation versus sensate athletes [3]. In working with the insensate athletes, medical providers need to look more carefully for occult musculoskeletal injuries because of their lack of sensation such as in the following injuries: fractures, subluxations, dislocations, and visceral injuries. The sensate athlete's injuries may have the same outcome as able-bodied athletes but possibly with greater consequences.

Almost all sit-skiing athletes are also wheelchair dependent and during off season train on land with wheelchairs, so they have an increased risk of shoulder injuries. These shoulder injuries range from but are not limited to the following: shoulder pain in general, rotator cuff injuries, subacromial bursitis, acromial clavicular joint abnormalities, coracoacromial ligament thickening, subacromial spurs, distal clavicle osteolysis, shoulder dislocations, shoulder subluxations, labral injuries, impingement syndrome, and biceps tendonitis [3]. The three most common injuries to the shoulder are the rotator cuff tendonitis, tear or impingement, labrum injury, and acromial clavicular joint separation.

Some of the risk factors to consider in these athletes for shoulder injuries are as follows: repetitive overuse motion, increased pressure in shoulder joint during propulsion as well as stopping with their wheelchairs or sit skies, muscular imbalances in the shoulder due to weakness, and cervical injuries affecting certain dermatomal patterns that stimulate muscles in the shoulder [3].

Overall, all upper limb injuries including shoulder injuries are very disabling because these athletes rely on their upper limb so much for weight bearing, transfers, and ambulation in addition to all of the demands placed on the upper limbs in the able-bodied populations. Therefore, it is important to be aware of all the presenting signs and symptoms of these shoulder injuries, which present similarly in the impaired athlete as they do in the nonimpaired athlete. They may or may not feel it as much or may actually feel it more if they have a history of an additional cervical injury previously affecting or not affecting sensation.

Despite increase repetitive overuse, sit ski athletes and wheelchair athletes do not have a higher incidence of shoulder pain than the nonathletic sit ski and wheelchair users. It has been found that participation in athletic competition appears to be protective from shoulder pain likely due to increased strength and endurance in the athletic population. Hopefully with better modifications of wheelchairs and sit skis, these athlete's shoulder injuries can be reduced by easier and more ideal propulsion techniques.

Besides a fracture, one needs to consider lateral epicondylitis. Other things to consider include medial epicondylitis, common extensor tendon strain, osteoarthritis, and olecranon bursitis. One of the main things to remember is ulnar nerve entrapment. Ulnar nerve entrapment is the second most common upper limb nerve entrapment syndrome (second only to carpal tunnel syndrome entrapping the medium nerve at the wrist). Any wheelchair user in general, athlete or nonathlete, is at a higher risk for ulnar neuropathy at the elbow [3, 11, 18, 19]. Ulnar nerve entrapment usually presents as numbness and tingling into the fifth finger and the ulnar side of the fourth finger. They usually have pain and tenderness in the ulnar groove, and if tapped, they may complain of the previously mentioned fingers feeling like they fall asleep, making the pain and numbness worse. This typically happens more when the elbow is bent. When the ulnar neuritis is very severe and/or chronic, they may also have weakness and atrophy with muscle wasting in the hand's intrinsic muscles, which may or may not be irreversible. They may also complain of difficulty with finger coordination. Diagnosis is made by the history, physical exam, X-rays, electrodiagnostic testing, MRI, and/or musculoskeletal ultrasound. Each treatment is tailored to the athlete's needs. Most wheelchair athletes or nonathletes will be nonmobile if they are required to restrict weight bearing. The other option may be limiting activity involving the upper limb, especially trying to avoid bending the elbow. Make sure they avoid leaning on it or putting any pressure on it as well. Additionally, one can wrap a towel around the elbow when they are asleep at night to keep from bending the elbow or wear an elbow pad backward. Other treatment options include NSAIDs, bracing/splinting, and nerve gliding exercises. Medical providers can also try neuroprolotherapy or if they are musculoskeletal ultrasound proficient, they can attempt nerve hydrodissection. When the above fails, then surgery is the next option. This includes a cubital tunnel release, ulnar nerve anterior transposition, or medial epicondylectomy.

With regard to wrist injuries, it is important to always consider carpal tunnel syndrome. This is the most common site of nerve entrapment, not only in the able-bodied but also the disabled person. Any athlete or nonathlete that uses a wheelchair has a prevalence of carpal tunnel syndrome (CTS) of approximately 49–73% [3, 11, 18, 19]. The main difference between wheelchair users with signs and symptoms and physical exam findings of CTS is that they have a lower functional status as compound to wheelchair users without CTS [3, 11, 18, 19]. The main presenting symptoms usually verified on physical examination with CTS are numbness and tingling in the thumb, index finger, middle finger, and radial half of the ring finger. Additionally, they may have decreased sensation in these digits as well. In many instances, depending on how long they have had CTS, they may have weakness in thumb abduction and palmar atrophy. Usually on physical examination, any pressure on the median nerve can reproduce the signs and symptoms. This includes bending the wrist (with Phalen's or reverse Phalen's test), as well as simply tapping or pushing on the nerve. They almost always have wrist pain with activity, especially doing activities that require wrist flexion. Another common complaint is nocturnal paresthesia, in which case, they have to wake up and stretch their wrists or shake out their hands and wrists. When working up CTS, due to insurance reasons, X-rays are obtained before electromyogram (EMG) and nerve conduction test/study (NCT/S) (EMG/NCT/S). In fully developed case of CTS, there is a triad of the following on MRI and ultrasound [20]:

1. Palmar bowing of the flexor retinaculum (>2 mm beyond a line connecting the pisiform and the scaphoid)
2. Distal flattening of the nerve
3. Enlargement (normal 9–11 mm^2) of the nerve proximal to the flexor retinaculum (most sensitive and specific)

There is a study which shows a 2 mm^2 difference in nerve cross section between the level of the pronator quadratus and carpal tunnel, which has a 99% sensitivity and 100% specificity.

The treatment for CTS is typically treated conservatively with life modifications and work modifications. This includes taking frequent breaks during work to rest their hands, avoiding activities that worsen their symptoms, applying cold packs to reduce occasional swelling, and doing a lot of stretching. Nonsurgical methods include the following: wrist splinting (especially nighttime splints in the cocked up extended position), NSAIDs, corticosteroid injections, diuretics to reduce peripheral edema, musculoskeletal ultrasound nerve hydrodissection, or all of these combined with physical therapy. If conservative methods fail, surgical options are endoscopic surgery, which uses a telescopic-like device with a tiny camera attached to it to see inside the carpal tunnel. The flexor retinaculum ligament is cut through with one or two incisions in the patient's hand or wrist. During postsurgery, one gradually needs to work back to their sport and normal use of their hand and wrist. It is important to avoid forceful hand motions or extreme wrist motions. Soreness or weakness can take from several weeks to a few months depending on how severe the signs and symptoms were before the surgery. However, if signs and symptoms were so extreme before the surgery, they may not go away completely after surgery. Generally, there is overall good results with hand therapy.

Peripheral nerve injuries can be from a traumatic neuroma which is hyperplasia of nerve fibers and their supporting tissues that develops with athletes with amputations because of the nerve risk of developing these painful conditions because of their sharp skis. Diagnosis is clinical, but sometimes one may need an MRI or musculoskeletal ultrasound. Treatment includes lidocaine patches, capsaicin cream, acetaminophen, NSAIDs, corticosteroid injections, neuropathic agents such as gabapentin or pregabalin, percutaneous ablation with alcohol, injections or radio frequency, nerve hydrodissection under ultrasound guidance, and/or surgical resection. However, there is an increased risk of neuroma development after surgery.

Peripheral nerve entrapment syndromes are common in athletes that use wheelchairs, sit skis, or crutches because there is an increased risk of development of upper limb peripheral neuropathies. This includes things such as median nerve neuropathy at the wrist, ulnar neuropathy at the wrist within Guyon's canal, ulnar neuropathy at the elbow within the cubital tunnel, brachial plexopathies, and other peripheral nerve injuries in the shoulder [3, 11, 18, 19]. Additionally, athletes with below-knee amputation are at risk of peripheral neuropathy at the fibular head due to improper prosthetic fit. These athletes need proper padding and equipment which is key to prevention. The treatment is resting and wrist splints to keep wrist in a neutral position. Other treatment options include NSAIDs, corticosteroid injections, nerve hydrodissection under ultrasound, and/or surgery. Surgical intervention is usually a last resort for athletes that have failed all other treatments. Other things to consider with wrist injury presenting as CTS include ulnar nerve entrapment at Guyon's canal [3], pronator teres syndrome, anterior interosseous nerve syndrome (Kiloh-Nevin syndrome), osteoarthritis, tendonitis, and De Quervain's tenosynovitis [3, 11, 18, 19].

When working with any wheelchair or sit-skiing athletes, it is important to always consider upper extremity fractures. These athletes are at an increased risk of upper limb fractures due to repetitive falls associated with wheelchair or sit-skiing sports and training. Hand position during propulsion in wheelchairs and balancing for sit skiing makes them more susceptible to injury from falling forward or to the side out of their wheelchair or sit ski. Additionally, they are at increased risk of fractures due to collisions with other nearby wheelchairs, sit skis, or other objects.

The relative high speeds of their sports also cause an increased risk for fractures. All of the previously stated information does not even take into consideration the standing athletes in the other classifications that experience repetitive falling. Some of these athletes have only one full arm because of their disability such as amputees. As a result, they have a higher chance of fracture since they only have one wrist. Additionally, the athletes skiing with only one leg and the visually impaired groups have higher risk of falls and wrist fractures. All fractures in the disable-bodied population and athletes should be treated with restricted upper limb weight bearing, similar to the able-bodied population. It is important to know that when working with this population of athletes, they may altogether become immobile if they are in a wheelchair when they sustain a fracture.

Another thing that must be considered in working with some of these adaptive athletes, especially the military wounded warriors, is heterotopic ossification [3, 21]. Heterotopic ossification (HO) is the presence of bone in soft tissue where bone usually does not exist, such as an abnormal anatomical site usually in the soft tissue. The acquired form of HO most frequently is seen with musculoskeletal trauma, spinal cord injury, and central nervous system injuries. It can be classified into three types as follows:

1. *Myositis ossificans progressiva (fibrodysplasia ossificans progressiva)*: this disorder is among the rarest genetic conditions with an incidence of one case per 2 million persons. It is an autosomal dominant with variable expression condition characterized by a recurrent painful soft tissue swelling that leads to HO and congenital malformation of the great toe. There is no treatment for this form and patients usually die eventually from restricted lung disease and pneumonia. But some patients live productive lives.
2. *Traumatic myositis ossificans*: a condition in which painful areas develop in muscle or soft tissue following a single blow to the area, a muscle tear, or repeated minor trauma. The painful area gradually develops tear or reputed more trauma. The painful area gradually develops tissue with cartilaginous consistency, and within 4–7 weeks, a solid mass of bone can be felt. Common sites of finding these are pectoralis major, biceps, and thigh muscles. A non-traumatic type of myositis ossificans also may exist.

3. *Neurogenic heterotopic ossificans*: the condition that comes to mind when the phrase heterotopic ossification is used. This type of HO develops traditionally following a traumatic brain injury (TBI), spinal cord injury (SCI), and total arthroplasty. It is also described with severe burns, strokes, encephalitis, polio, tetanus, tabes dorsalis, syringomyelia, and encephalopathy.

The most common populations involved in HO are TBI, SCI, brain patients, arthroplasty patients, and amputation patients. Usually HO develops around major joints restricting range of motion and limiting mobility. However, in amputations it can occur in injured tissues in residual limbs or it may not involve the joint at all.

Overall, the etiology of HO remains unknown. The only thing for sure is that trauma is one of the most important initiating factors. It usually presents 1–4 months after injury to the spinal cord, although it may occur as early as 19 days or as long as 1 year following injury. Depending on the condition, a fracture, surgery, or systemic illness may occur later. Most of the time, it is found incidentally afterward with X-rays. Heterotopic ossification always occurs below the level of the trauma in the spinal cord injuries. It also occurs more frequently in complete spinal cord injuries. Usually the hips are most commonly involved, especially the hip flexors and abductors (more frequently than extensors and adductors). The medial aspect of the knee is another common site. The shoulders and elbows are the most common upper extremity sites involved. With regard to those with head injury and strokes, HO almost always occurs on the affected side and mostly in patients with spasticity. Patients with neurological disorders of increased limb spasticity, decreased range of motion, and inflammatory signs near joints strongly suggest possibility of HO. Complications of HO may increase the risk of skin breakdown and cause significant pain with weight bearing.

The diagnosis of HO can be made clinically if there is a localized inflammatory reaction, palpable mass, or limited range of motion observed. Clinically, the onset of larger masses of HO is often characteristic of an inflammatory reaction. Sometimes fairly suddenly, a warm and swollen extremity becomes obvious and a fever is present. If the person still has sensation, it is very painful around the area of swelling. The swelling is usually localized, and within several days, a non-circumscribed mass is palpable within the edematous area. If the mass is adjacent to a joint, a gradual loss of passive range of motion may follow. With the development of early HO at the hip, a knee effusion may be noted as well at the knee.

HO is diagnosed clinically but labs should be ordered such as creatinine kinase (CK) and C-reactive protein (CRP). Even though CK is not specific for HO, it is of value in determining the severity of muscle involvement and in planning of the treatment of HO. C-reactive protein (CRP) helps determine if an acute inflammatory response is ongoing because CRP is one of the acute-phase proteins. Additionally, early on in the course of HO, it is recommended to use ultrasonography and bone scintigraphy because they are more highly sensitive in early cases of HO. It has been found that a three-phase bone scan shows a marked vascular blush and increased blood pool about the hips preceding the development of clinical HO by 2–4 weeks. Additionally, CTs, MRIs, and 3D stereolithography are most likely used to determine the anatomy around the area before one undergoes surgical intervention.

The treatment of HO has always been controversial because of the thought that overaggressive passive range of motion can lead to more spasticity and microfractures, but lack of passive range of motion exercises and continued immobilization can lead to overall decrease range of motion and ankyloses. The overall consensus currently is that during active inflammatory stage, the patient should rest the involved joint in a functional position and physical therapist should initiate gentle passive range of motion as soon as possible. Additional treatment of HO is with NSAIDs to help cut down the inflammation and reduce severity of HO. Specifically, nonselective NSAID indomethacin SR prescribed three times a week at a dose of 75 mg/day after a spinal cord injury (SCI) reduced incidence of HO by 2–3×. Additionally, a COX-2 inhibitor like Rofecoxib at 25 mg/day can reduce the risk of HO formation by 2.5 times. Another medical treatment is etidronate (Didronel). The bisphosphonate group of compounds helps with the reuptake of calcium such as etidronate disodium. However, once HO has developed to the point that it interferes significantly with one's functional capacity, the only treatment option is surgical excision. Usually the most common surgery required is an anterior wedge resection of the hip since it is the most commonly affected. Some other potential treatments are radiation therapy, with the overall goal to restore adequate levels of function.

One of the other medical conditions one will encounter in working with some of the Paralympic athletes is spasticity [3, 18, 19]. By definition, spasticity is a feature of altered skeletal muscle performance with a combination of paralysis, increased tendon reflex activity, and hypertonia. It also is referred to as unusual "tightness," "stiffness," or "pull" of muscles. Spasticity usually occurs after injury to the upper motor neuron. It is a very common complication of spinal cord injury (SCI), traumatic brain injury (TBI), cerebral vascular accident (CVA), or cerebral palsy (CP). Spasticity can potentially limit athletic participation by interfering with voluntary movements and restricting range of motion. Sometimes increase in spasticity may be an indication of a systemic or otherwise asymptomatic condition that may have few symptoms that are sensed by a patient with SCI. Examples of this include the following: infections, intra-abdominal pathology like appendicitis, skin breakdown, or bladder distension. When working with an athlete and there is a sudden increase in spasticity, it is important to search for an underlying pathology. Treatment varies for spasticity, but some of the oral medications used are as follows: baclofen, dantrolene, tizanidine, and benzodiazepine. Injectable medications such as botulinum toxin and intrathecal medication such as baclofen can also be used. If the athlete is resistant to conservative treatment, one can consider surgery for tendon lengthening. This may improve hygiene, activities of daily living, and functional activities including participation in athletics.

Additionally, it is important to consider arterial injury and compartment syndrome in the insensate athlete [3, 18, 19]. With regard to the vascular system in the sensate athlete, all the same concerns of injuries are the same as able-bodied athletes, except that the consequences possibly could be greater. Compartment syndrome can be a very painful and dangerous condition that is caused by some type of pressure buildup from internal bleeding or swelling of tissues usually after an injury. Impeding blood flow to and from the affected tissues (most commonly after fractures of arms or legs) can result from the following: crush injuries, burns, overly tight bandaging, prolonged compression of a limb while unconscious, surgery to blood vessels to arm or leg, blood clots in blood vessels, extremely vigorous exercise especially eccentric movements (extension under pressure), and taking anabolic steroids.

The most common presenting symptoms in compartment syndrome are severe pain in site of injury, deep aching in arms or legs that are affected, numbness, pins and needles sensation, and electricity-like pain in limbs [3, 18, 19]. Sometimes the pain is greater than one would expect for the severity of injury. Additionally, there is also significant weakness of the affected area and swelling, tightness, and bruising. It usually develops within a couple hours after an acute injury. There is also chronic compartment syndrome (aka exertional compartment syndrome) where there is worsening aching or cramping in the affected muscle(s) such as buttocks area, thigh area, or lower leg area (usually within a half hour of starting exercise). Symptoms go away with rest and muscle function remains normal. Exertional compartment syndrome can feel like shin splints and is often confused with medial tibial stress syndrome. There is also abdominal compartment syndrome which usually develops in people who are hospitalized, critically ill, or on life support. Athletes or patients usually cannot describe the symptoms. Usually a family member may notice a tense distended abdomen, urinary output when pushing on the abdomen, urine output slows or steps, and low blood pressure.

Compartment syndrome is diagnosed clinically and by physical examination. Sometimes it requires direct measurement of pressures inside the body of the compartment by a Stryker test. The physician inserts a needle into the compartment and monitors and records the pressure via a pressure monitor. A plastic catheter can also be inserted to monitor it continuously. Abdominal compartment syndrome is measured with a pressure monitor inserted into the bladder through urinary catheter. Overall laboratory and imaging tests can support the diagnosis of compartment syndrome, but no single test other than direct pressure measurement can make the diagnosis 100%. Treatment of acute compartment syndrome focuses on reducing the diagnostic pressure in the compartment. All dressings, casts, or splints that are constricting blood flow of affected body part must be removed. Most people require immediate surgery to reduce compartment pressures. A surgeon makes long incisions through the skin and fascia layer underneath (i.e., fasciotomy) releasing excessive pressure. Other supportive treatments include keeping the body part below the level of the heart to improve blood flow into the compartment, giving oxygen through the nose or mouth, giving fluids intravenously, and taking pain medications. Treatment of chronic compartment syndrome starts with individuals avoiding the activity that caused it, stretching, and physical therapy exercises, and there usually is improvement. Surgery is not as urgent as in acute cases. Abdominal compartment syndrome usually includes life support measures like mechanical ventilation, medicine to support blood pressure such as vasopressors, and kidney replacement therapy such as dialysis. Surgery to open abdominal cavity is needed at times. The surgery can be lifesaving but also can cause some complications.

When addressing the cardiopulmonary system, it is important to consider deep venous thromboses (DVTs) and pulmonary embolisms (PEs) which are treated the same as able-bodied athletes [3, 18, 19]. The big thing to consider is the cardiovascular effects of injury from spinal cord injury (SCI) and amputees [3, 18, 19]. Pulmonary considerations are the same for able bodied with regard to bronchitis, pneumonia, asthma, exercise-induced asthma, sinusitis, and allergies [3, 18, 19]. It is important to take into consideration the medications given because they may not be legal to take. The Olympics have strict rules with certain medications due to the potential to boost athletic performance. Therefore, any of these medications require a Therapeutic Use Exemption (TUE) form, especially for decongestants and inhaled medications. For example, some athletes may take asthma medications to boost their performance. This is called "boosting asthma." Albuterol has certain peptide hormones that increase bulk strength and oxygen carrying capacity in red blood cells. Therefore, all beta-2-agonists and their D-and-L isomers are bound. As a result, albuterol, formoterol, salmeterol, salbuterol, and termeterol may be used with a TUE form filled out but only in its initial form.

Blood doping is the practice of boosting the number of red blood cells in the blood stream. By boosting the number of red blood cells in the blood stream, more blood cells mean more oxygen is carried from the lungs to the muscles [18, 19, 22, 23]. Therefore, increasing the concentration of oxygen in the blood increases the athlete's aerobic capacity (VO2 Max) and endurance. And as a result, this improves their overall athletic performance. This boosting phenomenon can cause autonomic dysreflexia. Some spinal cord-injured athletes will attempt this type of boosting by intentionally inducing autonomic dysreflexia in order to improve their performance (Harris). This is a very dangerous thing that athletes attempt to do, and it can be potentially life threatening. Autonomic dysreflexia is a way to make the autonomic nervous system kick into over activity.

Autonomic dysreflexia decreases the central regulation of neurons stimulated below certain spinal regions resulting in abnormal sympathetic activity [3, 18, 19]. This sympathetic surge may cause life-threatening hypertension. Because the brain detects a hypertensive crisis via intact baroreceptors in the neck, this triggers a compensatory vagal/parasympathetic response which causes a decrease in heart rate, cardiac output, and blood pressure. Ultimately, all of the previously mentioned triggers vasodilation from the intact parasympathetic nerves responding above the injury. This causes abnormal vasodilation which in turn affects heart rate and cardiac output by lowering them, which is not sufficient enough to offset the sympathetic surge below the injury levels and hypertensive crisis persists. Basically a stimulus sends nerve impulses to the spinal cord via sympathetic outflow tracts in response to a noxious stimulus. This is then upregulated due to interruption of renal pathways after a spinal cord injury (especially at levels of T6 and above) because the impulses cannot travel upward any further as they are blocked by the lesion. Since the impulses cannot reach the brain, a reflex is activated that increases activity of the sympathetic portion of the autonomic nervous system. This increase in activity triggers spasms and narrowing of the blood vessels which causes a rise in blood pressure. Nerve receptors in the heart and blood vessels defect this rise in blood pressure and send a message to the brain, which entail sending a message to the heart, causing the heartbeat to slow down and the blood vessels above the level of the injury to dilate. Therefore, this increases blood flow, red blood cell count, and overall oxygenation. Some of the common symptoms of autonomic dysreflexia are headache, hypertension, paroxysmal hypertension, bradycardia, blurred vision, nasal congestion, anxiety, piloerection, facial flushing, and diaphoresis above the level of the injury. If hypertension continues to increase without treatment, stroke or death may occur (Pasquina). Some of the common noxious stimulus that leads to autonomic dysreflexia is tight clothing, urinary retention, fecal retention, renal stones, bladder stress, pressure ulcers, urinary tract infection, and/or intra-abdominal pathology (i.e., appendicitis). Treatment for autonomic dysreflexia is to get the athlete sitting upright and loosening all of their clothes. It is important to identify and eliminate the noxious stimulus. This includes things such as a distended bladder or distended or impacted bowel, hemorrhoids, UTI, tight clothing, gallstones, skin breakdown (i.e., ulcers, blisters, and sunburn), acute trauma, and DVT. For acute blood pressure control, chewable nifedipine or nitropaste can be used. One sometimes needs anal and/or intravenous antihypertensives with rapid onset and short duration.

Boosting is a prohibited form of intentionally inducing autonomic dysreflexia to improve sports performance [18, 19, 22, 23]. Athletes use techniques to produce "controlled" sympathetic surges via purposeful self-induced autonomic dysreflexia with noxious stimulus including but not limited to the following: clamping their urinary catheter, tightening leg straps, and shocking themselves with sharp objects in insensate locations. Boosting is a serious health risk to the athlete. Additionally, it is prohibited in sports competition and is deemed cheating. Athletes caught boosting will be disqualified and potentially banned from future competition.

Another major cardiopulmonary thing to consider is orthostatic hypotension. By definition, it is known also as postural hypotension, orthostasis, and colloquially as a head rush or a dizzy spell [3, 18, 19]. It is a form of low blood pressure brought on when a person's blood pressure falls suddenly when standing or stretching. Usually symptoms of orthostatic hypotension are light-headedness, dizziness, and syncope, especially if remaining concussed. Usually in the Paralympic athletes, it occurs after a spinal cord injury because of decreased sympathetic efferent activity in the vasculature below the level of the injury and also due to decreased reflex vasoconstriction. Subsequently, the result is venous pooling in dependent areas such as the lower limbs and abdomen with changes in position [3]. The best way to avoid this is prevention. It is important that athletes monitor their hydration and their salt supplementation. Athletes can also wear compression stockings and abdominal binders which are very beneficial. Some of the treatments for orthostatic hypertension are alpha-1-agonist medications such as midodrine (ProAmatine). The first-line treatment is from a man-made form of a glucocorticoid which actually is a synthetic corticosteroid with moderate potency and a much greater mineralocorticoid potency called fludrocortisone (Florinef). Additionally, the nonselective adrenergic agonist ephedrine, adrenalin, or adrenaline [3] helps because of its effects on the alpha and beta receptors. With all spinal cord injury athletes, one should attempt all non-pharmacologic prevention ahead of time before the use of any pharmacologic agents is considered.

Treating and being aware of the dermatologic system is very important in all Paralympic athletes or any adaptive athlete or person. It is crucial because a lot of these individuals cannot feel what is going on in their extremities. When working with the athletes that are sensate, the same worries one would have with able-bodied athletes should also be considered, but with greater consequences in the Paralympic athlete. In insensate athletes, it is important to be more diligent with regard to their extremities and the rest of their body. It is important to look for lacerations, decubital ulcers, rashes, and callous formation. Amputees need extra attention when examining their stumps due to verrucous hyperplasia, lichenification, epidermoid cysts, and/or contact dermatitis. Overall, it is important to consider skin breakdown. Following spinal cord injury athletes with insensate skin, there is a much greater risk of skin breakdown or a pressure ulcer. Usually the areas of highest risk of skin breakdown regardless of the level of their injury are the sacrum, coccyx, and ischial tuberosities. Specific athletic events may also have an increased risk of skin breakdown. Monoskiers also have a higher risk of skin breakdown. There is an increased risk of skin breakdown on the medial surface of their arms and forearms from rubbing against their wheelchairs during propulsion or getting bounced around in their buckets. These athletes may require customized equipment and padding to prevent skin breakdown in activity specifically by high-risk areas. Just as a note, wheelchair and monoskis athletes commonly sacrifice pressure relief for higher performance. Therefore, it is important to be vigilant in monitoring for skin breakdown. It is crucial to ensure that the athlete is changing position frequently and limiting time in their wheelchair and/or monoski. This is particularly essential when the athletes are transitioning to any new equipment. Prevention is the key in these athletes. As soon any sign of skin breakdown or pressure ulcer appears, it is essential to modify or restrict any weight bearing or athletic activities to prevent further injury. Pressure ulcers specifically can be a significant case of morbidity and mortality in the spinal cord-injured population.

Some specific dermatologic conditions that should be considered in this athletic population are verrucous hyperplasia, lichenification, epidermoid cyst, and contact dermatitis [3]. Furthermore, it is imperative to take into account the rare case of acroangiodermatitis (pseudo-Kaposi sarcoma). This is due to poorly fitted suction-socket-type devices used by amputees, especially in the lower limbs [2, 3, 18, 19].

Verrucous hyperplasia (papillomatosis cutis lymphostatica) is a wart or wartlike benign overgrowth of normal oil glands, usually sebaceous glands (aka shark skin) [3, 18, 19]. It is characterized by a sharp or blunt upward pressure of papillary projections of squamous epithelium. It results from inadequate socket wall contact with subsequent edema formation causing a wartlike skin overgrowth. This warty condition of a residual limb usually results from a chronic choke syndrome, which is a result of a proximal constriction that causes vascular insufficiency due to inadequate contact with the prosthesis. This can usually be treated by reestablishing the limb's total contact with the prosthesis. One may need to modify the socket to ensure distal compression and total contact within the socket. This will also help prevent acroangiodermatitis (pseudo-Kaposi sarcoma) which is hyperplasia of pre-existing vasculature as opposed to Kaposi sarcoma, which is a vascular proliferation independent of existing vessels. Acroangiodermatitis is usually seen as a complication of severe chronic venous stasis resulting from hypostasis and elevated venous pressure of lower legs and feet. This can be seen in amputees of lower extremity, especially in those with poorly fitting suction-type devices. The papules and plaques that develop are usually characterized by a purplish-blue to brown look. This is in contrast to the fleshy pale yellowish warty look of verrucous hyperplasia.

Lichenification is a skin condition that occurs in response to excessive itching or rubbing of the skin and results in an appearance of thick leathery hyperpigmented patches of the skin [3, 18, 19]. These usually occur because the outer layer of the skin naturally thickens with the extra irritation. It often happens in tandem with eczema or other skin disorders. The skin usually in this area has a burning or itching feeling and is very sore. Treating these areas usually require realigning the prosthetic and/or modifying the socket of the prosthetic to decrease pressure on the area. Sometimes topical over the counter or prescription medications will help relieve the itchy sensation. If symptoms are affecting sleep or constant, then using a type of sedative may be beneficial. Also steroids and NSAIDs help cut down on inflammation. Areas that are constantly being scratched after topical medications have been placed need to be covered with a nonsticking bandage to help stop the itching. This will also promote absorption of the topical medications. Furthermore, it is essential to address the athlete's diet in order to promote healthier skin and exercising.

Epidermoid cyst is a benign cyst usually found in the skin. The cyst develops out of ectodermal tissue and is histologically made of a thin layer of a squamous epithelium [3, 18, 19]. They typically result from implantation of epidermis into the dermis as in trauma or surgery but can also be caused by a blocked pore adjacent to a body piercing. In the adaptive athlete population, these cysts usually develop from the mechanical shear of the socket of the prosthetic on their stump. The cysts can get infected by bacteria and form a pimple-like shape. They usually present as a very painful pimple or cyst on an area of the body that has relatively little hair. Examples include areas where a prosthetic is located or the groin area in women, especially affecting the labia major or minor. Sometimes these cysts can be nonpainful and occasionally bigger cysts can release pus. Usually the initial treatment is to modify the wear of their prosthetic, modify the socket of the prosthetic, or not to wear it at all. One can also try treatment with a hot saline soak to help drain the cyst and use antibacterial or medicated talcum powder to help dry out the bump and reduce bacterial proliferation. These epidermal cysts often times need incised and drained. However, sometimes they are so large that a surgical resection is needed to release the adherence of the tumor capsule from the surrounding vital structures.

One of the most common dermatologic issues to deal with in this population is contact dermatitis [3, 18, 19]. Contact dermatitis is the development of a red itchy rash caused by a substance that comes into contact with your skin. This rash is not contagious or life threatening but can be very uncomfortable. There are many different causes such as soaps, cosmetics, fragrances, jewelry, and plants (i.e., poison ivy or poison oak). This usually results from irritation of the prosthetic's socket and/or liner. Usually one will present with erythematous pruritic areas. There may be swelling and bumps around the area that is tender to the touch or patients may complain of burning in this area. If it is a chronic contact dermatitis, the skin can be dry, cracked, and scaly in appearance. If it is a severe reaction, one may see blisters, draining fluid, and crusting. The overall severity of contact dermatitis depends on how long one has been exposed to the irritation. It also depends on the strength of the substance causing the rash. It is important to consider environmental factors such as temperature, air flow, and sweating to the area. In the adaptive athlete, the prosthetics irritation from the socket and/or liner is the most common irritant. The key to treatment and prevention is to first find out the cause. Afterward, it is important to eliminate the cause or modify the cause so it is not as irritating. This usually involves modifying the prosthetics socket and/or liner or having the individual modify the wear of the prosthetic. Sometimes simple things like adding antiperspirant to the area, within the prosthetics socket, and/or liner may help. Treatment for contact dermatitis includes the following: avoiding the irritant or allergen, prescription steroid creams, topical medications to help repair the skin and prevent relapse (i.e., those that affect immune system such as calcium inhibitors tacrolimus (Protopic) and pimecrolimus (Elidel)), and oral medications usually in severe cases (i.e., corticosteroids, antihistamines, and/or antibiotics).

The three most common infectious processes that occur in the Paralympic athlete are urinary tract infections, cellulitis, and septic arthritis [3]. These are treated the same for both sensate and insensate Paralympic athletes. The sensate athletes usually have greater consequences than the able-bodied athletes. It is also critical to remember that these conditions can cause autonomic dysreflexia. It is crucial to check that any medications prescribed for these conditions are not banned by WADA (World Anti-Doping Association). It is important to remember the medications banned by WADA. If needed, it will have to go through the TUE (Therapeutic Use Exemption) process. This is the only way an athlete can obtain approval to use a prescribed prohibited substance for the treatment of a legitimate medical condition. One must always keep this in mind when treating simple everyday conditions like allergies, asthma, and inflammation.

With regard to the endocrine system in the adaptive population, the adrenal system is mostly affected which causes hypotestosterone [3, 18, 19]. The hypothalamic pituitary thalamus axis is more susceptible to developing hypotestosterone in the adaptive population as compared to the able-bodied athletes. They are also at risk for hypogonadism and more susceptible to diabetes (especially type 2), insulin regulation issues, hypertension, metabolic syndrome, and osteoporosis. As a result of hypogonadism and hypotestosterone, one may experience the following: reduced libido/erectile dysfunction, reduced muscle mass and strength, increased adiposity, depressed mood, fatigue, and osteoporosis/low bone mass. The treatment for these endocrine issues is the same for adaptive athletes as they would be for able-bodied athletes and people.

The biggest concern and complication with any spinal cord injury athlete/nonathlete is osteoporosis [3, 18, 19]. Due to the injury and subsequent effect of decreased weight bearing, this predisposes them to osteoporosis. However, many risk factors are independent of alterations in weight bearing like severity of injury, spasticity, and time since injury [3]. Osteoporosis results in an increased risk of fracture in spinal cord injury athletes. Because most spinal cord-injured athletes have impaired sensation, they may not immediately complain of pain after the fracture. It is important to look for other warning signs like increased spasticity or autonomic dysreflexia. Prevention of osteoporosis is crucial in the adaptive athletes. Calcium with vitamin D supplementation is especially important in all adaptive athletes with spinal cord injuries. Additionally, medications such as bisphosphonates may also be used for prevention (i.e., Reclast, Boniva, Fosamax, and Actonel). The treatment of osteoporosis is the same for the adaptive athlete as the able-bodied athlete as well.

Various common gastrointestinal issues seen in the able-bodied population are usually the same in the Paralympic population. With regard to the gastrointestinal system, it is important to consider additional causes such as food poisoning, traveler's diarrhea (i.e., Montezuma's revenge), stomach flu, and food allergies. Also consider any new changes in medication.

The most common things in the genitourinary system that are seen in the Paralympic athletes are neurogenic bowel, neurogenic bladder, abdominal trauma, and pelvic trauma [3, 18, 19]. Many athletes with spinal cord injury have neurogenic bladder and/or bowel that result in the inability to spontaneously void or have a bowel movement. The more common of the two is neurogenic bladder. These athletes require bladder catheterization in order to empty their bladder. This can be accomplished by the athlete in various ways such as intermittent catheterization (every 4–6 h is the most preferred) per their own manual dexterity. For those with cervical spinal cord injuries or those that are not as good with their manual dexterity, a Foley catheter attached to a leg bag is used which allows continuous bladder drainage. There is also a suprapubic catheter, but this is not used much anymore.

Neurogenic bladder (flaccid or spastic bladder dysfunction) is caused by neurologic damage from SCI, brain damage, or nerve conditions [18, 19]. Symptoms can include overflow incontinence, frequency, urgency, urge incontinence, and retraction. It is seen commonly in spinal cord injury athletes. These athletes are at risk of serious complications such as recurrent infection, vesicoureteral reflex, and autonomic dysreflexia. Intermittent catheterization is the lowest risk in developing urinary tract infections compared to an indwelling Foley catheter or suprapubic catheter. Other risk factors of developing urinary tract infections is bladder sediments and bladder stress, as well as over distension of bladder, urethral infectious, and bladder carcinoma. These side effects and complications are reasons why it is so important to stress good genitourinary hygiene to the athletes. Unfortunately the immobility of elite athletes with neurogenic bladder to spontaneously void has implications for doping control because this is one of the major ways to trigger autonomic dysreflexia [3, 18, 19, 22, 23].

Neurogenic bowel occurs when a spinal cord injury interrupts communication between the nerves in the spinal cord that control the bladder/bowel function and the brain, resulting in bladder and bowel dysfunction [18, 19]. These occur because there is a loss of normal sensory or motor control to the upper and/or lower GI tract or both. The parasympathetic, sympathetic, and somatic nerves comprise the extrinsic nervous supply. Within this extrinsic nervous, the vagus nerve is parasympathetic and innervates the upper segments of the GI tract up to the splenic flexure. Additionally, within this extrinsic nervous supply, the pelvic splanchnic nerves carry parasympathetic fibers from the levels of S2–S4 spinal cord to the descending colon and rectum. The sympathetic fibers from the extrinsic nervous supply innervation are from the superior and inferior mesenteric nerves (T9–T12) and the hypogastric nerve (T12–L2). The hypogastric nerve specifically sends out sympathetic innervation from the L1, L2, and L3 spinal segments to the lower colon, rectum, and sphincters. The somatic innervation is from the pudendal nerve (S2–S4) which innervates the pelvic floor and external anal sphincter. This is a very complicated system and injury to the spinal cord at various levels or various disorders that affect the CNS can potentially affect the bowel function in various ways depending on the location and severity of the injury. Spinal cord lesions are classified as either located above the conus medullaris or located at the conus medullaris/cauda equina. A spinal cord lesion above the conus medullaris is an upper motor neuron (UMN) lesion and can cause loss of voluntary control, maintained reflex activity in the anorectic, increased colonic transit time, and constipation. Conversely a lesion at the level of the conus medullaris, cauda equina, or inferior splanchnic nerve is considered a lower motor neuron (LMN) lesion. This lesion would cause loss of voluntary control, loss of reflex activity in the anorectum, prolonged transit time, constipation, potentially rectal impaction, and reduced resting time in the anal sphincter.

It is very important for the athletes to practice safe use of assistance devices for bowel emptying. It is also vital for them to know efficient techniques for bowel emptying, digital stimulation, and the use of rectal suppository. It is essential to stress the importance of timing, regularity, and positioning in bowel evacuation. Any recommendations to help prevent bowel-related complications such as constipation, hemorrhoids, and impaction should be provided. These athletes are at greater risk for hospitalization due to impaction, megacolon, constipation, and volvulus. It is also important to emphasize proper hydration, fiber intake, and natural stool softeners to alleviate some of these problems. Patients with spinal cord injury report that bowel dysfunction is more problematic than bladder dysfunction, sexual dysfunction, pain, fatigue, or perception of body image. Overall, it is a significant contribution to a reduced quality of life because of its chronic daily nature.

Abdominal, urological, and genitourinary trauma account for approximately 12–18% of all traumas [2, 3, 18, 19]. Usually 13% of these are sports related. Genitourinary traumas are among the most common cause of abdominal injuries in sports [2, 3, 18, 19]. Overall, blunt trauma injuries from ski poles, ski gates, environmental, and the ground are more common than penetrating injuries. Renal injuries are usually the most common followed by testicular injuries. Ureter, bladder, and penis injuries are much more infrequent. Any type of riding sport or monoski has an increased risk of chronic microtraumas such as injuries of the bulbar urethra [3]. Usually renal injuries are from grade 1 to 2 lesions and do not require any surgical innervation. They most likely happen from crashes. Overall, winter sports have the second highest incidence of genitourinary injuries only behind cycling. In general, the incidence of genitourinary injuries in sports is low. Even in athletes with just one testicle, ovary, or kidney, there are studies that show the incidence of significant injury is rare. Injuries are treated on individual basis and there is no difference for the able-bodied athlete than the adaptive athlete. Generally, when preventative measures are taken against these types of sport-related injuries with protective equipment that protects the abdominal area (especially the flank area and the use of protective cups to protect external genitalia), studies show a significant reduction in incidence of abdominal and urogenital trauma. In athletes with only one testicle, ovary, or kidney, participation in sports which involves potential for contact or collision needs to be carefully assessed. Urogenital injuries or congenital defects/abnormalities/variations should not preclude sports participation to an appropriately informed and consented patient/athlete and family.

Another important factor when working with adaptive athletes is psychological issues [3, 18, 19]. This is especially important in athletes that become adaptive from the military. A medical provider should be able to handle and manage depression, anxiety, panic attacks, and post-traumatic stress disorder. Medications and treatment are typically the same, but a medical provider may need to get in touch with the athlete's psychiatrist(s) and/or psychologist(s). It is important for the athletes to have available phone numbers, if needed, to contact their appropriate sports psychiatrists and/or psychologists. These athletes' prior traumas can cause psychological needs. This is also similar to athletes who suffer from traumatic brain injuries. All of these psychological issues are treated the same in the able-bodied athletes, as well as the adaptive athletes. However, with the adaptive athlete, it is often more complex and complicated.

The next category to address medically is environmental issues. This includes, but is not limited to, the following: impaired thermoregulation, heat injuries, cold injuries, and various altitude illnesses, such as acute mountain sickness (AMS), high-altitude pulmonary edema (HAPE), and high-altitude cerebral edema (HACE) [3, 18, 19].

Impaired thermoregulation happens in athletes due to their spinal cord injuries. There is a disruption of their neuroregulatory systems that are ultimately involved in the control of body temperature [18, 19]. Consequently, what results is impaired shivering below their level of their spinal cord lesion and develop issues with producing heat to stay warm and impaired sweating, as well as vasodilation. Subsequently, when these issues develop, athletes have a difficult time staying cool or they are unable to do so. Interestingly, athletes with tetraplegia are not at an increased risk as compared to athletes with paraplegia [3]. This impaired thermoregulation happens because these athletes with various amputations result in a comparable decrease in their functional surface area which reduces the athlete's ability to dissipate heat. This causes them to be slow in acclimatization in hot and humid environments as well as cold environments. Paraplegic and tetraplegic athletes are expected to see greater increases in body temperature with exertion and greater decreases in temperature with exposure to cold weather. It is wise to check individual hydration status in all adaptive athletes using urine specific gravity and urine color charts prior to exercise and estimating sweat rates during exercise to implement individualized fluid hydration and fluid replacement.

When preventing impaired thermoregulation, a medical provider must have a heightened awareness and must monitor hydration, as well as use appropriate clothing and equipment depending on environmental conditions. It is important to stress availability of rehydration and avoid extra excess of temperature when possible. Sometimes athletes may purposefully refrain from drinking to avoid discomfort and lengthy bathroom breaks. However, usually unknown to them, they are increasing their risk of dehydration, urinary tract infections, and kidney stones. It is very important to stress prehydration before workouts and competition and vigorous fluid replacement post exercise which are key to ensuring a timely recovery. In addition, cranberry containing preparations (i.e., juice, concentrate, and tablets) may assist through their antimicrobial and antibacterial properties [18, 19]. Additionally, recent studies also show a glass of lemonade being effective in preventing urinary tract infections and kidney stones.

Athletes with spinal cord injuries have impaired sensation and require frequent visual monitoring to prevent cold injuries [3, 18, 19, 24]. The major complication in particular is frostbite. This is especially concerning during cold weather events. Frostbite or cold burn is the medical condition in which localized damage is caused to the skin and other tissues due to freezing. Frostbite is most likely to happen in body parts farthest from the heart and those with large exposed areas. The initial stages of frostbite are sometimes called frostnip. There are three main classifications for tissue damage caused by extreme cold as follows [18, 19]:

1. *Frostnip*: a superficial cracking of tissues without cellular destruction
2. *Chilblains*: superficial ulcers of the skin that occur when a predisposed individual is repeatedly exposed for cold
3. *Frostbite*: involves tissue destruction

There are four degrees of frostbite as follows [19]:

1. *First degree*: Frostnip only affects surface of the skin which is frozen. Usually starts out with itching and painful skin and then one develops white, red, and yellow patches and

becomes numb. Usually not damaged permanently. Sometimes long-term insensitivity to both heat and cold may develop.
2. *Second degree*: If first degree is not treated, then it can progress to second degree. The skin may freeze and harden, but deep tissues are not affected and remain soft and normal. Usually blisters (chilblains) 1–2 days after becoming frozen. Blisters may become hard and blackened but usually reappear worse than they actually are. Most injuries heal in a month but may become permanently insensitive to cold or heat.
3. *Third and fourth degrees*: If one still does not treat and second degree freezes further, frostbite occurs. Now muscles, tendons, blood vessels, and nerves all freeze. The skin is hard and feels waxy, and the affected area is usually temporarily damaged. In severe cases, it can be permanent. The deep frostbite may result in areas of purplish blisters which turn black and generally blood filled. Nerve damage develops and results in loss of feeling. This extreme frostbite may result in fingers and toes being amputated in areas that become gangrenous. If they go untreated now, they may fall off. The extent of damage to the area by freezing may not be able to be fully determined because it may take several months in order to fully assess the amount of damage done. After delays to remove dead tissues, this can ultimately cause of all types of nerve damage.

All types of frostbite or cold injury are caused by inadequate blood circulation when the ambient temperature drops below freezing. This causes the body to constrict one's circulation to its extremities on its own to preserve core temperature and fight hypothermia. In this scenario, the same factors that can lead to hypothermia (extreme cold, inadequate clothing, wet clothes, and wind chills) can contribute to frostbite. Poor circulation can also be cause by other factors such as clothes/shoes/boots being too tight, cramped positions, fatigue, certain medications, smoking, alcohol use, and/or diseases that affect blood vessels such as diabetes. Additionally, exposure to liquid nitrogen and other oxygenated liquids can cause frostbite, as well as prolonged contact with aerosol sprays.

It is crucial to decide how to treat and splint, if needed, based on the proximity to a stable warm environment. Rewarming the tissue too quickly can cause it to refreeze, and if one moves it too much, it can damage tissue even more. Splinting or wrapping frostbitten extremities are recommended to prevent movement. Do not allow rubbing, massaging, or stroking the area in attempt to rewarm the area since it can be harmful. Warming can be achieved in two ways: passively and actively. Passive rewarming is using body heat or ambient room temperature including wrapping blankets or moving to warmer environment. Active rewarming is the direct addition of heat to a person, in addition to passive rewarming. Usually it needs to be done in a hospital, but it can be done outside of one. It can be challenging because one needs to warm the injured tissue quickly and yet do so in a way that will not harm it. The faster the tissue is thawed, the less likely it is damaged. One can immerse injured tissue in water that is between 40 and 42°C (104 and 108°F). Warming peripheral tissues can increase blood flow back to body's core. However, there is a risk of developing abnormal heart rhythms when shunting blood back and forth from the periphery to the core and vice versa. Sometimes it is too late and requires surgery via debridement of necrotic tissue. Sometimes amputation is required, but this is usually delayed, with exception of infectious gas gangrene. This is why surgeons use the phrase "frozen in January amputate in July." If caught early enough, all cases of frostbite have a good chance. However, a number of long-term sequelae can occur, including but not limited to the following: transient or permanent changes in sensation, paresthesia, increased sweating, cancers, and bone destruction/arthritis in the affected area(s).

Heat injuries/heat illness/heat-related illness is also a concern [3, 18, 19, 25]. It may be ironic that heat-related injuries/illness can occur in the winter since it is cold. The number one cause is due to lack of fluid intake (dehydration). It can be also be related to an athlete overdressing or that the environment one is skiing in is warmer than expected. Other causes of heat illness are medication. The three main forms of heat injury are heat cramps, heat exhaustion (exercise-associated collapse), and heatstroke. However, there are many other forms like heat edema, heat rash, and heat tetany. All of these are a spectrum of disorders due to environmental exposure to heat or self-induced by accident. The above in descending order from most severe to least severe are as follows [18, 19, 25]:

Heatstroke: body temperature of >40°C (104 °F) due to environmental heat exposure with lack of thermoregulation. Symptoms include dry skin, rapid pulse (tachycardia), strong pulse, dizziness, high breathing rate (tachypnea), disorientation, confusion/irritation, seizure, hypotension (low BP), and unconsciousness/coma which is a medical emergency.

Heat exhaustion (exercise-associated collapse (EAC)): can be a precursor to heatstroke. The symptoms include heavy excessive sweating, rapid breathing, rapid or fast weak pulse, dizziness, headache, nausea, vomiting, muscle cramps, or pulselessness.

Heat syncope: fainting as a result of overheating.

Heat edema: peripheral edema especially in the feet more so than hands as result of overheating and lack of salt balance.

Heat cramps: muscle pains that happen during heavy exercises in hot weather or overdressed individuals usually affecting the gastrocnemius and hamstrings.

Heat rash: skin irritation from excessive sweating.

Heat tetany: usually results from short periods of stress in intense heat. Symptoms may include hyperventilation, respiratory problems, numbness or tingling, or muscle spasms.

Treatment for heat injuries is dependent in what stage one is in, usually determined by rectal temperature. In general, it is important for active cooling and to push fluids by mouth. Lay them on their back with their legs raised. It is pertinent to stretch, if there is cramping. If they do not get better in 10 min, they may need IV fluids or cold water submersion. The key to prevention is to know the environment one is competing in and dress and hydrate properly with a good balance of fluids and electrolytes. The other key thing is avoiding medications that increase the risk of heat illness (i.e., antihypertensives, diuretics, and anticholinergics). The challenge with this is a lot of the adaptive athletes may need or rely on these medications due to their conditions.

Acute mountain sickness (AMS) is physical distress from difficulty adjusting to lower oxygen pressure at high altitude [18, 19, 26–30]. It usually happens above 8000 ft. (2400 m). It is usually caused by reduced air pressure and lower oxygen levels at exposure to high altitudes. Usually, the faster one ascends to high altitude without acclimatization, the more likely one is to get acute mountain sickness. There is a higher risk of acute mountain sickness if one lives at or near sea level and travels to high altitudes or has a previous history of the illness. There is an increased risk of acute mountain sickness in many winter sports and competitions at high altitudes. Acute mountain sickness is thought to be caused by alterations in the blood-brain barrier and cerebral vasculature that occurs at high altitudes [3]. Because of this pathophysiology, spinal cord injury athletes given their altered neurophysiology and anatomy may be at a higher risk of acute mountain sickness [3]. Athletes and travelers in general are at risk for more frequent complications when traveling at high altitudes because they do it more often. Additionally symptoms may be more likely to occur in individuals with less cerebrospinal fluid volume and less ability to accommodate increased brain volume. Usually the development of symptoms depends on the speed of ascent and how hard one exerts themselves. Symptoms can range from mild to life threatening. Acute mountain sickness can affect the nervous system, lungs, muscles, and heart. Most cases are relatively mild. Symptoms of mild to moderate acute mountain sickness may include the following: headache, nausea, vomiting, dizziness, light-headedness, fatigue, loss of appetite, rapid pulse, and shortness of breath with exertion. In more severe cases of acute mountain sickness, the following symptoms can also occur: blue color to the skin (cyanosis), chest tightness and/or congestion, confusion, cough, coughing up blood, decreased consciousness or withdrawal from social interaction, gray and/or pale complexion, cannot walk in a straight line and/or walk at all, and shortness of breath at rest. Overall the most common symptoms are fatigue and weakness. The importance in catching acute mountain sickness early is so it does not develop or progress into one of its two more dangerous subsets which are high-altitude pulmonary edema (HAPE) and high-altitude cerebral edema (HACE).

High-altitude pulmonary edema (HAPE) is a life-threatening form of non-cardiogenic pulmonary edema (i.e., fluid accumulation in the lungs). This can occur in healthy individuals at altitudes typically above 2500 m (8200 ft.) [31]. It can also occur at lower altitudes between 1500 m and 2500 m (4900 and 8200 ft.) if a person is more susceptible or vulnerable like the Paralympic athlete. The problem is that what makes one susceptible to HAPE is currently unknown. HAPE currently remains the major cause of death related to high-altitude exposure, and it has a very high mortality rate in the absence of timely emergency treatment. The symptoms are defined by the criteria set by the Lake Louise Consensus or Definition for HAPE [26]. They are based on physiological and symptomatic changes according to the altitude involved. One needs at least two of the following symptoms: difficulty breathing at rest (dyspnea), cough, weakness or decreased exercise performance, chest tightness, or congestion. One also needs at least two of the following signs: crackles or wheezing while breathing in at least one lung field, central cyanosis (blue skin color), tachypnea (rapid shallow breathing), and tachycardia (rapid heart rate).

The thought is that the initial cause of HAPE is the shortage of oxygen caused by the lower air pressure at high altitudes [31, 32]. The mechanism of action of how this happens is unknown. However, the following two processes are thought to be important:

1. Increased pulmonary arterial and capillary pressures (i.e., pulmonary hypertension) secondary to hypoxic pulmonary vasoconstriction [33]
2. An idiopathic noninflammatory increase in the permeability of the vascular endothelium [34]

These are just two hypotheses because even though higher pulmonary arterial pressures are associated with the development of HAPE, the pressure of pulmonary hypertension may not itself be sufficient to explain the development of the edema. Severe pulmonary hypertension can exist in the absence of clinical HAPE in subjects at high altitude [35]. The standard and most important treatment is to descend to a lower altitude as quickly as possible, preferably by at least 1000 m. Also, if possible one should be given oxygen as soon as possible. Usually the signs and symptoms improve quickly with descent. However, some symptoms that are severe can continue for several days. The mainstay of drug treatments in which there is strong medical evidence is dexamethasone and nifedipine. Additionally, phosphodiesterase inhibitors such as sildenafil and tadalafil are also effective but potentially can worsen the headache of mountain sickness.

High-altitude cerebral edema (HACE) is a medical condition in which the brain swells with fluid because of the physiological effects of traveling to a high altitude [11]. It generally appears in patients who have acute mountain sickness that has progressively gotten worse and involves disorientation, lethargy, and nausea among other signs and symptoms. HACE usually occurs when the body fails to acclimate while ascending to a higher altitude. It seems to be vasogenic edema which is fluid penetration across the blood-brain barrier. However, additionally cytotoxic edema and cellular retention of fluids also may play a role as well [11]. Individuals that develop this condition must descend immediately to a lower altitude or coma or death can occur.

The primary cause of HACE is hypoxia (oxygen deprivation). This occurs after the body is exposed to low-oxygen environments and before it acclimatizes. It can also occur with prolonged exertion in low-oxygen environments and leads to serious hypocapnia (lower carbon dioxide in the blood stream) which also may play a role in HACE. All these factors cause the brain to swell with fluid from vasogenic edema and penetration of the blood-brain barrier [11, 27, 28, 36–39]. Consequently, this results in severe impairments if the swelling is left untreated and can cause death by brain herniation. It is currently unknown as to what makes one more vulnerable to HACE than others.

Early signs and symptoms of HACE generally correspond with those of moderate to severe acute mountain sickness [36]. Initial symptoms include the following: confusion, loss of consciousness [37], fever, ataxia [36], photophobia, rapid heartbeat [38], lassitude, and altered mental state [36]. Usually, regardless of one's will to survive, physical activity eventually will slow down significantly or stop altogether, and severe headaches develop and one loses the ability to sit up [38]. Retinal venous dilation occurs is 59% of people [39]. Some of the rare symptoms are as follows: brisk deep tendon reflexes, retinal hemorrhages, blurred vision, extension plantar reflexes, ocular paralysis [38], and sometimes cranial nerve palsies. Treatment of HACE is rapid descent and supplemental oxygen to prevent mortality. Early recognition of signs and symptoms are the key to survival. Additionally, one can treat with dexamethasone and if possible placing a person in a portable hyperbaric chamber (Gamow bag) for temporary relief. The most important treatment factor is to get one down off the mountain for evacuation for hospital care. Some medications are sometimes helpful, which includes diuretics, sildenafil [39], tadalafil [39], and theophylline [27]. HACE is a life-threatening condition unlike acute mountain sickness. It must be treated within 24 h. All altitude-related conditions AMS, HACE, and HAPE can be prevented with proper acclimatization by not ascending more than 1000 m (3300 ft.) daily and not sleeping at a greater height than 300 m (980 ft.) more than the previous night is recommended. Prophylaxis is usually with acetazolamide or dexamethasone; however, acetazolamide is usually preferred.

Concussion is the most common type of traumatic brain injury. It is currently called a mild traumatic brain injury. It is defined as a head injury with a temporary loss of brain function causing a variety of physical, cognitive, and emotional symptoms that are hard to recognize at times. The exact cause of a concussion and its symptoms are not clear, but the current belief is that damage is due to stretching of axons and changes in ion channels. Additionally, it is now thought that structural and neurophysiologic factors may both be responsible for the effects of concussion. Since the brain is surrounded by cerebrospinal fluid, it can only protect one from light trauma. More severe impacts or forces associated with rapid acceleration and deceleration is not able to be absorbed by this small cushion [40]. Concussions are not just from head impacts alone. It is also from blunt trauma to the chest or back causing the head to snap forward, backward, or most likely a rotatory motion. It is more thought to come from a plethora of forces on the brain causing linear, rotational, angular, or most likely a combination of them [41]. The major component of force is now thought to be the amount of rotational force causing the most issues [42]. The more the rotational force there is, the concussion will be more severe. The parts of the brain that are most affected by these rotational forces are the midbrain and diencephalon [43, 44]. It is thought that the forces disrupt the normal cellular activities in the reticular activating system located in these areas and that their disruptions cause loss of consciousness. Other parts of the brain affected are the upper part of the brainstem, the fornix, the corpus callosum, the temporal lobe, and the frontal lobe [45]. The higher angular acceleration increases one's risk of acquiring a concussion [44]. Mild traumatic brain injury can alter the brain's physiology for hours, days, or years setting into motion a variety of pathological events [46]. These events start with the disruption of the cell membrane of nerve cells. Ultimately, this affects potassium and, thus, the sodium-potassium ion pump resulting in excessive ATP consumption and glucose utilization. Consequently, this causes lactate to accumulate and CSF to decrease leading to an energy crises. The body then goes into a lower metabolic state for up to 4–6 weeks [47]. Separately, another pathway affecting calcium causes accumulation in cells impairing oxidative metabolism affecting other biochemical pathways resulting in cell death. The above is the current thought on causes of concussion. Diagnosis is based on physical examination findings, most importantly the duration of unconsciousness, neurological findings, post-traumatic amnesia, Glasgow coma scale, balance testing, vestibulo-ocular testing, neuropsychological testing, SCAT3, and sometimes computerized testing. There are multiple factors affecting one's diagnosis. Most concussions cannot be detected with MRI or CT scans.

There is no longer a classification system in place for concussions because no single definition of concussion, minor head injury, or mild traumatic brain injury is accepted. It is now thought to be considered a complex pathophysiological process affecting the brain induced by traumatic biomechanical forces. Red flag warning signs of more serious concussions include the following: seizure, worsening headache, difficulty waking up, double vision, difficulty recognizing people or places, repeated vomiting, focal neurological problems, and not acting like one's usual self [48]. Concussions are associated with a variety of symptoms which can rapidly worsen after injury and just as rapidly subside. They usually resolve in days or weeks. Each concussion and how its symptoms present and play out are case dependent. Headache is by far the most common symptom. Other common findings include the following: post-traumatic amnesia (retrograde and anterograde), confusion, dizziness, vomiting, nausea, lack of motor coordination, difficulty balancing, other movement or sensation issues, light sensitivity (photophobia), seeing bright lights, bright light sensitivity, double vision, blurry vision, tinnitus (ringing in ears), smelling issues, loud noise sensitivity (phonophobia), unconsciousness, seizures, cognitive and emotional issues such as being overly happy or sad, mood changes, restlessness, lethargy, and irritability. The symptoms of concussion are extremely vast and can be from one extreme to the other. Since there are so many symptoms of concussion, it may be best to categorize concussion based on the symptoms as follows [49]:

1. *Cervicogenic*: dysfunction to the cervical spine
2. *Cognitive*: attention problems, dysfunction, fogginess, fatigue, cognitive slowing, etc.
3. *Emotionality*: emotional, sadness, nervousness, irritability, etc.
4. *Sleep disturbance*: difficulty falling asleep, sleeping less than usual, etc.
5. *Vestibular*: ability of ocular motor and neurological systems and body (eyes, brain, and body) to work together
6. *Visual*: ability of ophthalmologic system to work appropriately with vergence and divergence, smooth pursuits, saccades, accommodations, and convergence and if vestibulo-ocular reflexes and vestibulo-ocular reflex cancelations are appropriate

When doing the physical examination for concussion, it is important to always include vitals, speech, gait analysis, deep tendon reflexes (DTRs), musculoskeletal examination for strength of upper extremity and lower extremity bilateral, neurological for sensation upper extremity and lower extremity bilateral, and cranial nerve examination. Additionally, on physical examination one should complete the following: Romberg test (balance and motor conduction), pronator drift test (upper motor neuron testing), tandem gait walk test (coordination), heel to shin test (balance and coordination), finger to nose test (point to pain coordination), and finally VOMS testing (vestibular ocular motor screening).

The VOMS testing is a multifactorial test which is made up of the following physical examination testing [49, 50]:

1. *Smooth pursuits*: extraocular testing.
2. *Saccades testing*: looking for point-to-point discrimination in horizontal and vertical planes (fingers 12 in. apart and patient looks between them for 15 s). Look for latency of onset, speed, accuracy, and conjugate movement. Test failure is if there is delayed, inaccurate saccades, or disconjugate eye movement.
3. *Vestibulo-ocular reflex (VOR) gaze stability*: the ability to focus on a stationary object while moving the head without blurriness or dizziness. Performed with the examiners finger stationary and patient moving head side to side while fixating on the stationary finger. Examinee should be tested in the horizontal and vertical plane for 15 s. Look for the examinee's eyes' inability to hold focus.
4. *Fixation suppression test (VOR cancelation)*: response to optokinetic stimulation (relating

to the occurrence of twitchings or movements of the eye when many objects are viewed). Patient/athlete focuses on his own thumb stuck out in front of him at arm's length moving the whole body side to side following and focusing on his own thumb. Examiner is looking for the examinee's eyes' inability to follow a fixated object.

5. *Near point convergence dysfunction test*: patient/athlete focuses on the writing on a pen 6 cm (2 in.) from rose bridge and should be able to read it. Examiner moves pen in past 6 cm and out past 6 cm and is asking when it is blurry and when it is easy to read. Examiner is looking for diplopia at greater than 6 cm and the inability of the eyes to converge. An abnormal finding is usually blurred or usually double vision and the eyes have a tendency to drift outward (exophoria).
6. *Test for near point of accommodation (push up test)*: it is best to use small letter(s) (approximately 0.4 or 0.5 m) to help better control accommodation. Have examinee cover one eye and slowly move object with letter(s) on it closer to their face and the examining eye until they come blurry. Measure the distance the letter(s) become blurry. They should be able to accommodate normally and see clear at 12 cm. You can fatigue their accommodation system by bringing letter(s) in closer.

Ocular motor assessment can be accomplished with the King-Devick test which is a quick and objective computer tablet-based test based on the measurement of the speed and accuracy of rapid number naming (i.e., reading aloud a series of single digit numbers from left to right and line to line). The King-Devick test looks specifically at oculomotor function and saccades and detects impairments of eye movements, attention, language, and other correlates of suboptimal brain function. Then examinee gets one practice trial and three test trials. The timings added from all three tests after concussion is often compared to baseline of time necessitated to take the test when not concussed. The King-Devick test currently shows the greatest accuracy and lowest risk of false positives [49].

Vestibular examination can be done multiple ways; with the easiest being the modified BESS (Balance Error Scoring System) test [49, 50]. The BESS test can be performed in nearly any environment and takes approximately 10 min to conduct. The BESS test regimen consists of three to four different stances depending on if doing dominant and nondominant leg for single stance or just nondominant leg for single stance. Each part of the test lasts 20 s with their eyes closed. The parts of the test are as follows: one double-leg stance, single-leg stance right, single-leg stance left, and tandem stance dominant leg forward on two surfaces stable/firm and unstable/foam versus the modified BESS (MBESS test) test only on a firm surface. The overall score is determined by the amount of errors recorded during balance conditions, which is one point for each error. The more errors that are performed, the higher the problem with balance and coordination post-concussion.

Some other tests that can be done as part of the vestibular examination are as follows [49, 50]:

1. *BPPV (benign paroxysmal positional vertigo test) (aka Dix-Hallpike test)*: Patient starts sitting up and then is put into supine position and the head is turned right 45° and extended apparently 20° backward and eyes are observed for approximately 30 s for nystagmus. Then patient is sat back up and eyes observed for nystagmus, and then the same is done with head turned to the left. Positive test consists of a burst of nystagmus (jumping of the eyes) in classic positional BPPV, the eyes jumps upward as well as twist so that the top part of the eye jumps toward the downside. This is the definitive test for BPPV.
2. *Sway balance test* is a mobile software test in which one can use the built-in motion detection of a mobile device to measure postural sway. Athlete/patient instructed to press the mobile device against his or her chest with both hands while performing a five-test protocol that includes a combination of bipedal stance, tandem stance, and single-leg stance positions. It measures thoracic postural sway using built-in motion senses. Upon completion

a sway sum is displayed off 100-point scale. Less than 80 is usually found abnormal.
3. *Testing platforms (i.e., Biosway).*
4. *Computerized dynamic posturography programs.*
5. *Patient self-report (activity-specific confidence scale or falls efficacy scale)* can also be used depending on the physician's confidence in athlete.

Overall, no matter what, almost 80–90% of all concussions are resolved in a short 7–10-day period. Sometimes with concussions CT scans are ordered, but most of the time, they are negative. The reason they are ordered is to look for a possible acute epidural or subdural hemorrhage. Some additional neuroimaging considerations for lingering concussions are MRIs with DTI, PET scan, magnetic resonance spectroscopy, and functional MRI (fMRI). Most concussions when followed with a concussion specialist will usually consist of some type of neuropsychological assessment. Some people in sports medicine believe that the gold standard for concussions should be having a neuropsychologist trained in concussions as part of the team. However, most sports medicine-trained physicians are trained in the management of concussions or at least have a concussion group/protocol setup. The most common test performed now is a computer neuropsychological test such as ImPACT [51], Cogsports, Head Modes, CNS vitals, as well as others. These neuropsychological tests look at the following categories: verbal memory, visual memory, visual motor speed component, and reaction time. The overall treatment goal for concussion is to prevent second impact syndrome, cumulative effects of concussion, and post-concussion syndrome and alleviate concussion symptoms [49, 50]. First-line treatment is to have the athlete at complete mental and physical rest. It is important to alleviate as much as possible physical exertion, TV, video games, cell phones, loud noises, bright lights, and excessive reading. Vestibular therapy, ocular therapy, balance therapy, and physical therapy should be started as soon as possible. When on the road with athletes for long trips, a medical provider must be comfortable with handling this type of treatment. The team physician is typically the only one that can help the athlete go through a proper safe return to play protocol. As with all able-bodied athletes, the treatment for adaptive athletes' post-concussion is the same. However, due to some of their disabilities, signs and symptoms can be more or less than normal, and the return to play protocol activities may or may not need to be modified. Additionally, one must know when to refer their athletes for further treatment for recovery from concussion to a psychiatrist, especially if the athlete already has significant premorbid psychiatric issues or if psychological issues are developing from the concussion. Early recognition and intervention is the key to treatment. It is important to refer to a formal neuropsychologist, especially if the athlete is not recovering as fast as one would expect and testing scores are not improving on computerized neuropsychological testing like ImPACT [51]. It is crucial to know when to refer to an optometrist or ophthalmologist if one is suspicious for a newly diagnosed neuro-optometric condition which has developed or an already predetermined visual issue previously corrected has gotten worse. Pharmacological treatment should be performed usually in the following two instances [49, 50]: (1) control of specific symptoms in concussion and (2) to modify the underlying pathophysiology of concussion to shorten symptom duration.

Initially at the onset of concussion, all NSAIDs should be avoided as they can cause rebound headache [49, 50]. Use acetaminophen only, especially for those under 18 years old. Besides acetaminophen for those older than 18 years old, Ultracet can be used as long as there is no previous history of a seizure disorder. Additionally, consider starting on vitamin and supplement therapy as soon as possible [49, 50]. Some of *these supplements are riboflavin* (B2) and magnesium (Mg++), coenzyme Q10, vitamin E, omega-3s, and *Ginkgo biloba*. Additionally, make sure the athlete is off as much caffeine as possible. After the first couple of weeks, one can add naproxen twice a day if needed [49]. Sometimes if cervicogenic symptoms are causing the concussion, muscle relaxants are beneficial throughout the day or one can be taken a couple hours before bedtime. Due to the extent of cervicogenic headaches, the athlete may benefit from manual therapy, ROM exercises, osteopathic manipulation therapy (OMT), strength training, acupuncture, and/or injections [49, 50]. Also for headache prophylaxis or ongoing headaches, one can try the following [49, 50]: propranolol, verapamil, amitriptyline, Lexapro, or Zoloft. Even though they are all used off label for headache prophylaxis, they have been shown to be beneficial. As stated earlier, some emotional symptoms may develop which may require one to take care of them with a temporary use of a SSRI like Lexapro or Zoloft. Sometimes off-label medications are also needed to help with cognitive symptoms such as amantadine (Symmetrel), Concerta, and Strattera. Finally, if there is an ongoing sleep issue after the concussion, one may consider supplementing with an over-the-counter melatonin to help regulate the patient's sleep status post-concussion or use a prescribed medication such as trazodone.

Generally, there is no right or wrong treatment for concussions and each athlete should be treated individually. Once most of the symptoms have resolved with rest and clinically the athlete is doing better, it is important to test the athlete with exertion. If their symptoms do not come back, take them through the six-stage progressive return to play protocol as laid out in the Vienna/Prague/Zurich concussion protocol statement [27–29, 39, 52]. Just remember that there is no blueprint right or wrong for concussions. One cannot base it on simply what a computer tells them or what the guidelines say. A medical provider should do what is best for their concussed athlete with the overall treatment basis of "Do No Harm."

From all injuries in the Paralympic athletes that are competing in downhill skiing, the two pathologies that account for the most total injuries is knee ligaments, especially ACL, (approximately 51%) and upper extremity contusions [53]. In snowboarding, the two most common pathologies that accumulated approximately 49% of total injuries are upper extremity contusions and wrist fractures [53]. The probability of injuries in skiers with an approximate mean age of 33 in males is 52.44% and females is 47.95% versus 69% and 29.93% for snowboarders with a mean age of 26 in males and females, respectively [53]. Technology for alpine skiing has helped with some of the knee injuries because now there is a three-model binding which helped cut back on tibial fractures. However, since they have been incorporated, there have been more MCL and/or ACL injuries with the highest incidences during giant slalom season. Overall, 15% of all Paralympic injuries in alpine skiing and snowboarding are head injuries [53]. Additionally, 60% of all accidental deaths in all winter sports are related to head trauma. Between 1995 and 2010 when there was an approximate 50–75% increase in helmet usage, the percentages of head injuries decreased by more than 20% [53]. Furthermore, potentially serious head injuries expressed in mild traumatic brain injuries (MTBI) or traumatic brain injury (TBI) diminished by approximately 64%. Overall, in the Paralympic alpine skiing population, injuries are common in the following classifications from most to least: LW-11, LW-12, LW-2, B2, B3, LW-6/8-2, and the LW-10/2 with most injuries more likely in males [53]. Even in these classifications, the lower extremities were mostly affected at approximately 48.48% and then upper extremities at approximately 25.76% [53]. Almost all of these injuries are from contact with each other or the ground, an object, or gates. Additionally, most of these injuries happen significantly more in training than in competition and most of the time cause the athlete to miss >28 days of their sport [53].

There is a lot to consider medically when working with alpine skiing and snowboarding. If a physician is comfortable treating and managing them in the office setting, then he/she should be comfortable managing, stabilizing, and treating them while traveling with the team. While traveling with the team, the physician is also rehabbing them and making sure they are comfortable and/or stable until they get back to their home personal physicians. When traveling with

Fig. 23.34 (**a**) Photograph courtesy of YouaPa Yang (medical bag). (**b**) Photograph courtesy of YouaPa Yang (medical bag). (**c**) Photograph courtesy of Brian J. Juriga (medical bag)

the team, it is imperative that a medical bag be taken and it should consist of an array of medical tools and equipment that are potentially needed for the diverse injuries that can be sustained by the Paralympic athletes (Fig. 23.34a–c). All Paralympic athletes usually have international medical coverage if needed, but sometimes they need to be medevacked back to the states or their country of origin. The most important thing to always remember in alpine events is to be prepared for the unexpected.

Conclusion

This chapter has attempted to cultivate a greater understanding of adaptive alpine skiing and snowboarding, the array of medical testing, assessment, and possible injuries that can be encountered in Paralympic athletes. Being a Paralympic physician is one of the most challenging and demanding positions one can attain, as well as one of the most rewarding (Fig. 23.35a–d). Working with these extraordinary athletes challenges a physician to consistently assess and expand his/her knowledge, skills, and ultimately expand his/her growth as a medical provider. One of the greatest rewards is found in the relationship, care, and close connection for each athlete and their individual needs. It is important to be well rounded, open to change, and be as versatile as possible. It is essential to be able to quickly treat and make a diagnosis in any situation that may arise as one can never predict what will happen on the road or on the mountain. It has been one of the greatest journeys in my professional medical career, and I am grateful for every opportunity to have worked alongside these amazing and exceptional athletes.

Fig. 23.35
(**a**) Photograph courtesy of Brian J. Juriga. (**b**) Photograph courtesy of Brian J. Juriga. (**c**) Photograph courtesy of Brian J. Juriga. (**d**) Photograph courtesy of Brian J. Juriga

Fig. 23.35 (continued)

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24 Adaptive Throwing Sports: Discus, Javelin, Shot Put, and Boccia

Michael Auriemma and Arthur Jason De Luigi

Classification Overview

Adaptive sports allow for athletic participation by individuals with differing impairments and disabilities. Impairments refer to abnormal anatomic or physiologic structure or function, while disabilities refer to functional limitations that are a result of impairments. For the purpose of classification, the International Paralympic Committee recognizes six basic impairment groups, as listed in Table 24.1.

The International Paralympic Committee Classification Code provides a universal template for further sub-classification within each sport that takes into account both the anatomical and functional limitations of the athlete. The purpose of subclassification is to allow for even competition by categorizing athletes in reference to the total impact of their impairment(s) [1]. Generally speaking, the greater the degree of disability present, the lower the athlete's classification.

Table 24.1 Impairment groups

Amputee
Cerebral palsy
Visual impairment
Spinal cord injury
Intellectual disability
Les Autres ("The Others," including dwarfism and multiple sclerosis)

M. Auriemma, MD (✉)
MedStar Georgetown/National Rehabilitation Hospital, Washington, DC, USA
e-mail: michael.auriemma@medstar.net

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA
e-mail: ajweege@yahoo.com

Field Events: Discus, Javelin, and Shot Put

In the sports of discus, javelin, and shot put, the goal is to hurl, throw, or put an object as far as possible. In the adaptive form of these sports, the distance is then converted to a score based on the athlete's classification, thus allowing for fair competition among athletes with differing levels of impairment. Athletes participating in all field events, including discus, javelin, and shot put, are classified in the F10s through F50s. The "F" stands for "field," and the number that follows signifies level of disability. The F10s are athletes with visual impairments; the F20s are athletes with intellectual impairment; the F30s are athletes with varying degrees of motor dysfunction, including cerebral palsy; the F40s are athletes with short stature, limb deficiencies, or amputations; and the F50s are wheelchair athletes, including tetraplegics and paraplegics [2]. As previously mentioned, the lower the classification number within each grouping, the greater the degree of disability. For more details on the classifications, see Table 24.2.

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_24

Table 24.2 Field classifications for discus, javelin, and shot put [2]

Classification	Description
F11	No light perception or small amount of light perception but incapable of recognizing the shape of a hand at any distance or in any direction
F12	Can recognize shape of hand and perceive clearly up to 20/600. Visual field is <5°
F13	Can recognize shape of hand and perceive clearly >20/600 but ≤20/200. Visual field is >5° but <20°
F20	IQ <75, with significant limitations in adaptive behavior, and age of onset before 18 years old
F31–34	Athetosis, ataxia, and/or hypertonia. Compete in seated position. Demonstrate increasing trunk and upper extremity control from 31 to 34
F35	Athetosis, ataxia, and/or hypertonia. Compete standing. Moderate dysfunction of lower limbs, good functional strength in upper limbs
F36	Athetosis, ataxia, and/or hypertonia. Compete standing. Involuntary movement affects all four limbs, cannot remain still
F37	Athetosis, ataxia, and/or hypertonia. Compete standing. Movement/coordination difficulties affect non-dominant side of the body
F38	Athetosis, ataxia, and/or hypertonia. Compete standing. Minimal functional loss, generally affecting only one limb
F40–41	Short stature
F42	Single side above knee amputation (AKA) + arm deficiency. Compete standing
F43	Double below knee amputation (BKA). Compete standing
F44	Single BKA. Compete standing
F45	Double above or below elbow amputation
F46	Single above or below elbow amputation
F51–54	No leg or trunk function. Demonstrate increasing degrees of shoulder, arm, and hand function from 51 to 54. Includes tetraplegics
F55–58	Upper limb function intact. Demonstrate increasing degrees of trunk and leg function from 55 to 58

Adaptive Discus

The purpose of discus is to throw a circular biconvex disk as far as possible from a designated circular throwing area. In an able-bodied throw, the athlete begins by facing away from the throwing field before forcefully spinning 1.5 times and then releasing the discus in a sidearm fashion, allowing the discus to spin off the fingers. In adaptive discus, some of the standing athletes use the able-bodied spin technique (see Fig. 24.1), while others use a more stationary standing technique, relying solely on trunk and upper extremity rotation to generate torque. The seated athletes also rely solely on trunk and upper extremity rotation as they throw from a stationary throwing frame. In both able-bodied and adaptive discus, all throws are made from a caged enclosure designed to prevent errant throws from traveling toward spectators or other participants. For a throw to count, the discus must land within a marked landing sector. The actual discuses used in adaptive sport weigh between 0.750 and 2 kg, depending on the classification, as compared to the able-bodied population which uses 1 kg discuses for women and 2 kg discuses for men [2, 3].

Adaptive Javelin

The purpose of javelin is to throw the spear-like javelin as far as possible from a designated throwing area. A runway leads up to the throwing area, and able-bodied athletes will run up this track before launching the javelin. The javelin is held by a single hand at the grip site near the center of the javelin and must be thrown over the shoulder or upper part of the throwing arm. For a throw to count, the tip of the javelin must be the first part to land on the ground within the marked landing sector. In adaptive javelin, the standing athletes use the runway just as the able-bodied athletes do, while the seated athletes throw from a stationary throwing frame (see Fig. 24.2). The actual javelins

Fig. 24.1 An F44 discus thrower (Photograph provided by the United States Olympic Committee. Photograph by Joe Kusumoto)

Fig. 24.2 An F58 javelin thrower (Photograph provided by the United States Olympic Committee. Photograph by Becky Miller)

used in adaptive sport are 2.0–2.7 m in length and weigh between 500 and 800 g, depending on the classification. Comparatively in the able-bodied population, female competitors use 2.2–2.3 m javelins that weigh 600 g and male competitors use 2.6–2.7 m javelins that weigh 800 g [2, 4].

Adaptive Shot Put

The purpose of shot put is to throw a spherical metal shot as far as possible from a designated circular throwing area. The shot is held in close proximity to the neck/chin region and cannot be dropped below this position during the throw. In an able-bodied throw, or put, the athlete begins by facing away from the throwing field, just like discus. From here, the athlete may execute one of two force-generating techniques, the "spin" or the "glide." The "spin" is essentially the same as the discus technique, with the athlete forcefully spinning 1.5 times before releasing the shot. The "glide" consists of a forceful turn from the rear-facing position, pushing off the dominant leg, before releasing the shot. The put itself is executed by one hand, in a pushing fashion, with the point of release being above the level of the shoulder. For a put to count, the shot must land within a marked landing sector. In adaptive shot put, the standing athletes use the able-bodied "spin" or "glide" techniques, while the seated athletes put from a stationary throwing frame (see Fig. 24.3). The puts used in adaptive sport weigh between 2.0 and 7.260 kg, depending on the classification, whereas in the able-bodied population, female competitors use a 4.0 kg shot and male competitors use a 7.260 kg shot [2, 5].

Boccia

Boccia is the adaptive sport equivalent of bocce. It was originally developed for athletes with cerebral palsy but is now inclusive of athletes of other impairment groups including stroke, traumatic brain injury (TBI), spinal cord injury (SCI), muscular dystrophy, and multiple sclerosis. It is played indoors on a flat, smooth surface and features individual as well as team play. Each individual, or team, has six leather balls (either red or blue), and the purpose is to land the ball as close as possible to the "Jack" or white target ball. To begin the game, or match, the red individual (or team)

Fig. 24.3 An F57 shot putter (Photograph provided by the United States Olympic Committee. Photograph by Becky Miller)

throws the Jack out onto the court. Athletes, depending on their impairments, are permitted to throw, kick, or use an assistive device known as a pointer to propel the ball from a designated throwing area. After throwing the Jack, that same player then throws his or her first red ball toward the Jack. Blue then throws their first ball. Whichever ball is closer to the Jack identifies the "in team." The "in team" watches as the other team throws their balls one by one until they either displace the "in team" or run out of balls, after which the other team resumes throwing. A round, or "end," is completed after all balls are thrown. At this point, the score is tallied. The individual, or team, that is closest to the Jack will score as many points as they have balls closer to the Jack than their opponent's closest ball [1, 6].

Each match consists of four to six ends depending on the number of players per team (individuals and pairs play four ends, teams of three play six ends). Each player, or team, throws six balls per end (i.e., an individual throws six balls, pairs throw three each, and teams of three throw two each). The winning individual, or team, is the one with the most points at the end. If there's a tie, a tie-breaker end is played. If at any time during an end the Jack is pushed or rolls out of bounds, the Jack gets placed in the center of the court and the closest ball determines the new "in team" [1, 6].

Individual and team play is comprised of seven different divisions, four divisions of individual play and three divisions of team play (two for pairs and one for teams of three). For a description of each division, please see Table 24.3. The actual boccia balls

Table 24.3 Boccia divisions [6]

Division	Description
Individual BC 1	Sport assistant may provide assistance to athlete, such as passing athlete the ball, adjusting wheelchair orientation, or shaping the ball, but the athlete must specifically instruct these actions and the assistant must remain in a designated area behind the throwing area
Individual BC 2	No assistance from a sport assistant is permitted during a match. The referee, however, can provide some assistance, such as handing the athlete a ball that was accidentally dropped
Individual BC 3	A ramp is used as an assistive device to propel the ball (see Fig. 24.4). A sport assistant can assist in orienting the wheelchair or ramp or can roll the ball, but the athlete must specifically instruct these actions. Also, the assistant cannot look at the court and must keep their back toward the court
Individual BC 4	Athletes with locomotor disabilities of a non-cerebral origin and athletes that "throw" with their foot instead of their hand. The BC 4 foot players may receive assistance from a sport assistant as the BC 1 players do
Pairs BC 3	At least one of the two players must have cerebral palsy. Otherwise they operate under the same rules as Individual BC 3
Pairs BC 4	Same rules as Individual BC 4
Team (BC 1 or BC 2)	Teams of three composed of BC 1 and BC 2 athletes. There must be at least one BC 1 athlete on the court for each team at all times

Fig. 24.4 A BC 3 boccia athlete (Photograph provided by the United States Olympic Committee. Photograph by Shelly Higgins)

weigh 275 ± 12 g with a circumference of 270 ± 8 mm [6].

Adaptive Equipment

Depending on the athlete's impairment(s), adaptive equipment may include prosthetic limbs or wheelchairs. Beyond these, the adaptive equipment is more sport specific. As previously mentioned under the field events, seated athletes, specifically F31–34 and F51–58, utilize a throwing frame in discus, javelin, and shot put. The throwing frame is secured to the ground and the seat height cannot exceed 75 cm. Holding bars may be present which can be held by the hand of the non-throwing arm to assist in maintaining balance and generating greater force. There may also be footplates present for added support and stability. Straps can be placed over the thighs and/or pelvis. The use of gloves as an adaptive device to improve grip is permitted for classes F51–53 only [2].

For boccia, specific adaptive equipment may include ramps and pointers, as previously mentioned. BC 3 athletes who cannot throw or kick the boccia ball are eligible to use ramps and pointers. Ramps are slide-like structures that the boccia ball can be "launched" from, and pointers are devices fixed to the athlete's head, mouth, or arm to push the ball down the ramp [6].

Sports Medicine Overview

Like all athletes, adaptive throwers are subject to injury. Many adaptive throwers have unique medical issues related to their underlying health conditions. It is important to be aware of these issues first and foremost. In addition to underlying medical issues, adaptive athletes are at risk for injuries related to both their disability and sport-specific activity.

Unique Medical Issues

Athletes that compete in adaptive sports often have unique medical issues based on the very health conditions that precipitate their impairments and disabilities, particularly the athletes with spinal cord injuries. Regardless of what sport they are participating in, athletes with spinal cord injuries are at varying risk, based on the level of lesion, for developing urinary stones, bladder infections, respiratory infections, pressure sores, and autonomic dysfunction [7–10]. While insensate individuals are at higher risk of pressure sores/ulcers at baseline, there are added risk factors which are pertinent to adaptive athletes that include increased moisture from sweating and repeated movements during sport activity [7, 11]. All athletes competing in wheelchairs are potentially subjected to this risk. Therefore, it is important for the athletes to have adequate cushioning of the buttocks, frequent pressure reliefs, high-performance moisture-wicking clothing, and optimal nutrition [10, 11]. Autonomic dysfunction, in the form of poor vasoregulation and impaired innervation of sweat glands, places the athlete at risk of hyperthermia, dehydration, and intolerance of environmental extremes, emphasizing the need for proper fluid hydration before, during, and after competition [7, 9, 10]. Another unique medical issue worth noting is the increased seizure risk associated with cerebral palsy. Athletes with cerebral palsy may be at higher risk as the seizure threshold may be lowered through stress encountered during competition, fatigue from training, or dehydration [7]. It is important to keep these underlying health issues in mind when caring for adaptive athletes.

Injuries by Disability

Underlying disability can predispose the adaptive athlete to specific injury patterns. Generally speaking, upper extremity injuries are more common in wheelchair athletes, while lower extremity injuries are more common in ambulatory disabled athletes [8, 12–14]. More specifically, a study that looked at the 1996 Paralympics found that among US competitors with soft tissue injuries, wheelchair athletes had a predilection for shoulder, arm-elbow, and forearm-wrist injuries; visually impaired athletes a predilection for hip-thigh, cervicothoracic region, and shoulder injuries; and cerebral palsy athletes a predilection for lumbar region, foot-toe, and ankle injuries [14]. A separate study that looked at the 2004 Paralympic Games found that injury occurrence was different based on classification, with more injuries occurring among track/field (T/F) 11–13, followed by T/F 40–46, T/F 51–58, T/F 32–38, and finally BC 1–4 [15].

Among disabled athletes, the wheelchair athlete warrants special mention because of the factor of wheelchair use and the unique risk factor for injury from the wheelchair. Repeated contact with the wheelchair push rims for purposes of propulsion increases the risk of blister formation on the hands and fingers, though this is more common in wheelchair racers. To prevent further irritation, blisters should be treated with petroleum jelly and a tape or gauze dressing, while the use of gloves may prevent blister formation from occurring [10, 11].

In addition to blisters, soft tissue injuries and skin lacerations/abrasions are the most prevalent injuries sustained by wheelchair athletes, with estimates of 33% of all injuries being soft tissue injuries [10, 11, 16]. Soft tissue injuries, including strains, sprains, bursitis, tendinopathies, and peripheral nerve entrapments, are most likely to affect the shoulders, elbows, wrists, and hands, with the shoulders being the most commonly affected [11, 17]. The risk of shoulder pathology, including rotator cuff impingement, rotator cuff tears, glenohumeral instability, and biceps tendonitis, is unusually high among wheelchair users. Though this risk is essentially the same for wheelchair athletes in general compared to non-athletic wheelchair users, wheelchair athletes competing in overhead sports appear to be at increased risk [10, 17–19]. Many of these injuries are the result of overuse and correlate with duration of impairment, duration of wheelchair use, and more training hours per week [16–18]. Muscle imbalances of the shoulder girdle may be correlated with wheelchair-related overuse injuries. Training programs should therefore focus on shoulder flexibility and strengthening of the shoulder adductors, internal and external rotators, supraspinatus, pectoralis major, triceps, and anterior deltoid muscles [17, 20].

Wheelchair posture may also play a role in injury. Proper seating and positioning helps provide adequate trunk stability, alleviating the need of contributions from the upper extremities to trunk stabilization [17]. This positioning can become compromised as an athlete fatigues, resulting in greater reliance on the upper extremities to the maintenance of stability, thus also increasing susceptibility to injury [17]. Rest and recovery can offset fatigue, decreasing the risk of injury. Further injury prevention is possible through optimal wheelchair design, proper propulsion technique, and modification of everyday activities to decrease repetitive movements. For athletic use, wheelchair weight and rolling resistance are minimized, wheels are aligned as close to the center of mass as possible, and high pressure tires are used, all in an effort to make propulsion less physically demanding [21]. Proper wheelchair propulsion technique should be taught, where shoulder impingement is minimized through an emphasis on scapular retraction rather than internal rotation with scapular protraction [17]. Finally, activity modification, such as storing household items at shoulder level or below so as to avoid unnecessary overhead activity, should be encouraged [17].

Injuries by Sport

Sport-specific activity is an important contributor to injury patterns. While this is an under-researched topic, particularly in the adaptive athlete population, the research that is available suggests that the injury distribution for specific adaptive sports is comparable to that of the able-bodied form of the same sports [8, 22, 23]. This should be intuitive when the adaptive form of the sport is similar in nature to the able-bodied form of the sport. The track and field throwing events, for instance, entail the same basic throwing motions as the able-bodied forms—standing and seated discus throwing consist of truncal and upper extremity rotation, standing and seated shot putting consist of either rotational or linear actions depending on the technique used (spin versus glide), and standing and seated javelin throwing consist of linear movement. While the specific biomechanics involved differ for each of these throws, what they have in common is the dynamic acceleration of a weighted object, the performance of which places great stress on joints, ligaments, and tendons [24].

Discus

Throwers in general are at risk for developing blisters and finger injuries, but this is of particular concern in discus throwers who carry an increased risk of finger sprains and dislocations [25]. Taping the fingers can help prevent these injuries, but fingers may only be taped individually. Taping multiple fingers together is considered a rules violation as this may assist in the throw [25]. Other less frequently reported injuries include pectoralis major tendon rupture, Achilles tendon rupture, and patellar joint dislocation [24].

A pectoralis major tendon rupture can be partial or complete and may result from forceful adduction of the arm during the discus throw. The athlete generally experiences sudden onset of pain at the medial aspect of the proximal arm. Physical exam should reveal weakness and pain on resisted contraction of the pectoralis major. Ultrasound and/or MRI can assist in diagnosis. Partial tears can be treated with ice and progressive rehabilitation with physical therapy, while complete tears require surgical repair [26].

An Achilles tendon rupture and patellar dislocation are injuries associated with the spinning action used to generate momentum in the ambulatory discus throwers. A rupture of the Achilles tendon is marked by immediate loss of function in terms of the ability to complete plantar flexion of the ankle with or without associated pain. On exam, a gap may be palpable in the tendon proximal to its insertion on the calcaneus. A special diagnostic test is the Simmonds-Thompson test, where the athlete is placed in the prone position on an examination table and the calf of the affected leg is squeezed by the examiner. The absence of induced plantar flexion is a positive test and suggests Achilles rupture. Another test to assist in diagnosis is the Matles test, where a prone patient will be asked to flex the knee, and the examiner will observe the position of the foot. An intact tendon would cause the foot to plantar flexion due to the two-joint length of the gastrocnemius muscle, whereas in a patient with a tendon tear, the foot will remain in neutral or will dorsiflex due to gravity. Surgical repair is usually performed, followed by casting, functional bracing, and progressive rehabilitation.

A patellar dislocation usually involves lateral displacement of the patella with disruption of the medial patellofemoral ligament. Hemarthrosis with edema can occur acutely. The athlete usually presents with severe pain and describes the leg as "giving way." Oftentimes the dislocation reduces spontaneously. On exam, attempting to contract the quadriceps will aggravate the pain. The lateral patellar apprehension test, where the examiner pushes the patella laterally, is positive if laxity is noted and the patient expresses discomfort. Associated findings can include osteochondral fractures; thus it is recommended that the athlete undergo emergent X-rays with anteroposterior, lateral, skyline, and intercondylar views. Generally, first-time dislocations are treated non-operatively, unless there is also an osteochondral fracture. The rehabilitation course is extensive.

Javelin

Of the throwing events, javelin is the truest overhead sport. Being an overhead sport, there is an increased risk of injury involving the shoulder and elbow. Compared to other overhead throwing sports, the javelin is heavier, and this may contribute to injury risk. Among shoulder injuries, rotator cuff pathology is frequent [27–29]. MRI studies have revealed that it is very common for even junior javelin throwers to have posterior-superior intraosseous cysts of the humeral head, located near the insertion points of the supraspinatus and infraspinatus tendons [30, 31]. While these cysts may be present in the absence of pain or shoulder dysfunction, they may be early manifestations of shoulder pathology secondary to overuse and may predispose to rotator cuff injury [30, 31]. Additional findings in javelin throwers include reduced internal range of motion with increased external range of motion and greater anterior tilt and retraction of the scapula in the throwing shoulder compared to the non-dominant shoulder [30, 32]. These findings suggest that javelin throwing leads to structural and biomechanical changes, and these changes occur early on.

Repetitive use increases the risk of tendinopathy and impingement, with the supraspinatus tendon being the most commonly involved. The athlete will usually report pain during overhead activity and resolution of pain when at rest. A painful arc through arm abduction may be seen on exam, and special tests indicative of impingement can be performed, including the Neer's and Hawkins' tests. Weakness on supraspinatus testing is more indicative of a significant tear. Ultrasound and/or MRI can be utilized to visualize whether a tear is present. Immediate treatment consists of ice and rest. For rotator cuff tendinopathy, a corticosteroid injection into the subacromial space can help relieve pain and facilitate a physical therapy program that focuses on strengthening of the rotator cuff and improved scapulohumeral rhythm. For partial tears, physical therapy can be attempted, while full thickness tears require surgical repair.

The elbow is also susceptible to overuse injuries. The overhead throwing motion inevitably involves humeral-induced torque that transmits a valgus force on the elbow. Elbow extension counters this force while also inducing tensile stress along the medial elbow, shearing stress along the posterior elbow, and compressing stress along the lateral elbow [33, 34]. These forces make the overhead athlete's elbow susceptible to injury of the ulnar collateral ligament (UCL), ulnar neuritis, valgus extension overload syndrome, medial epicondylitis, flexor-pronator injury, medial epicondyle apophysitis or avulsion, triceps tendon rupture, olecranon stress fractures, and osteochondritis dissecans of the capitellum [24, 35].

The javelin throwing motion places recurrent valgus stress on the medial elbow. Incorrect form in which the elbow comes around at the level of the shoulder places even greater strain on the UCL, increasing the risk of strain or rupture [25]. Symptoms of a UCL rupture include a popping sensation with immediate pain at the medial elbow and instability with loss of function. On exam, the athlete is often tender to palpation at the medial epicondyle and valgus stress will indicate laxity. If a rupture is suspected, X-rays are indicated to evaluate for a possible bony avulsion. Tears of the UCL most commonly involve the anterior bundle. Partial UCL tears can be managed conservatively, with relative rest for 6–12 weeks and no throwing for at least the first 6 weeks [35]. Nonsteroidal anti-inflammatory drugs (NSAIDs) are indicated to reduce inflammation, and a hinged elbow brace may be worn to restrict extension. Early rehabilitation focuses on range of motion (ROM) and strengthening of the shoulder and elbow ROM. Strength training at the elbow can be initiated after the athlete has regained full pain-free ROM at the elbow. Platelet-rich plasma treatments may play a role in speeding recovery [36]. Complete tears require surgical reconstruction. Current evidence suggests that javelin throwers recover well following ulnar collateral ligament reconstruction, with average time to return to throwing being 8 months and average time to return to previous level of competition being 15 months [37]. It has been recommended that postoperative rehabilitation protocols be more cautious than other overhead throwing sports, with longer delay before initiating a throwing program, due to the increased weight of the javelin compared to a baseball [37].

Valgus instability at the medial elbow as a result of UCL compromise makes the athlete susceptible to additional pathology, including ulnar neuritis and valgus extension overload syndrome. At baseline, the ulnar nerve is susceptible to traction during overhead throwing. In the setting of reduced stability secondary to UCL injury, a greater valgus stress may be transmitted to the ulnar nerve, inducing a greater degree of traction. This repetitive traction, in addition to the inflammation that accompanies a UCL injury, can irritate the ulnar nerve, resulting in ulnar neuritis. Symptoms include pain and/or numbness along the ulnar aspect of the forearm with radiation into digits 4 and 5 of the hand. On exam, ulnar neuritis can be assessed by having the athlete flex maximally at the elbow while extending at the wrist and holding that position for 1 minute. Findings suggestive of ulnar neuritis include onset of aching pain along the ulnar aspect of the forearm to digits 4 and 5 of the hand. Non-operative treatment includes relative rest, NSAIDs, and physical therapy. Surgical treatment, if necessary, involves alleviating any compressive forces on the ulnar nerve and possibly transposing the actual nerve.

Valgus extension overload syndrome is another repetitive use injury that athletes are more susceptible to in the setting of underlying UCL compromise. The syndrome is marked by posteromedial elbow pain during late elbow extension and wrist flexion on follow-through during the throwing motion. Associated findings include synovitis, olecranon osteophytes, and loose bodies in the olecranon fossa that form as a result of posterior and lateral forces. The presence of loose bodies can cause catching and locking of the elbow. Non-operative treatment consists of rest, NSAIDs, cryotherapy, iontophoresis, and physical therapy with a focus on eccentric strengthening of elbow flexors to better control elbow extension. Surgery is indicated if non-operative treatment fails and involves the debridement and removal of loose bodies.

Even with an intact UCL, repetitive valgus stress can result in additional injuries, including medial epicondylitis, flexor-pronator injury, and medial epicondyle apophysitis or avulsion. When performed correctly, the javelin is thrown over the shoulder with elbow extension, forearm pronation, and wrist flexion. The repeated actions of forearm pronation and wrist flexion put stress on the common flexor tendon and can result in medial epicondylitis, marked by dull, aching pain in the medial elbow that is exacerbated during forearm acceleration and wrist follow-through. The pain is often reproducible on exam with resisted wrist flexion and forearm pronation. Medial epicondylitis may be difficult to clinically differentiate from a UCL sprain, but the greatest point of tenderness should be more distal to the medial epicondyle versus more posterior to the medial epicondyle in a UCL injury. An MRI is appropriate for differentiating between the two conditions. Non-operative treatment is preferred with relative rest, ice, NSAIDs, and physical therapy.

Another overuse injury involving the wrist flexor and pronator complex is the aptly named flexor-pronator injury. Overhead athletes often experience hypertrophy of the medial forearm flexor-pronator musculature which can result in compression of the median nerve. The compression generally causes difficult to localize pain over the anterior surface of the forearm that is worsened with pronation and wrist flexion. Proper rest and stretching are usually enough to correct this condition.

A condition that is unique to younger overhead athletes with open growth plates is medial epicondyle apophysitis or avulsion. As previously mentioned, the valgus stress to the medial elbow gets transmitted to the UCL and common flexor tendon, which are both attached to the medial epicondyle. This stress can be transmitted to the medial epicondylar physis, causing inflammation and possibly even an avulsion fracture. The athlete presents with point tenderness over the medial epicondyle and pain on valgus stress of the elbow. An avulsion fracture can also cause edema and decreased ROM on elbow extension. X-rays should be obtained. Rest is indicated for apophysitis, and depending on the severity of the avulsion fracture, surgery may be required.

Injuries to the elbow that are dependent on forces other than valgus stress include triceps tendon rupture, olecranon stress fractures, and osteochondritis dissecans of the capitellum. Repeated elbow extension can result in a triceps tendon rupture. This is usually marked by acute pain and diminished function of the elbow. On exam a gap may be appreciated at the insertion point of the tendon on the olecranon. Non-operative treatment can be attempted in incomplete tears, while surgical repair is indicated for complete tears. Postoperatively the elbow should be splinted and then transitioned to a removable brace for the first 6–8 weeks. Rehabilitation can be initiated at 4–6 weeks postoperatively. Olecranon stress fractures can be induced by repetitive contraction of the triceps tendon. It tends to occur more proximally with symptoms and signs being post-throwing pain and tenderness on palpation of the olecranon. If suspected, MRI should be ordered to confirm the diagnosis. Initial treatment consists of rest and immobilization with a splint in about 20° of elbow flexion. Rehabilitation can begin after 4 weeks. More severe stress fractures may require surgical fixation. Finally, osteochondritis dissecans (OCD) of the capitellum can be the result of repetitive compression of the radial head on the capitellum of the humerus secondary to overhead throwing. This condition is more likely to develop if there is underlying ischemia. Signs suggestive of the diagnosis include lateral elbow pain on palpation of the lateral elbow and valgus stress. Reduced ROM is another possible finding. Typical X-ray findings include subchondral cysts and flattening of the capitellum if advanced. If caught early, OCD of the capitellum can be treated with rest for 6 weeks followed by progressive physical therapy. Surgery is indicated if the condition is more advanced, loose bodies are present, or if conservative treatment fails.

Shot Put

The shot put consists of trunk rotation and forward thrust that is transmitted from the shoulder through the elbow and wrist to the third metacarpophalangeal joint [38]. This motion places a great deal of stress on the wrist, making sprains of this joint common. Taping of the wrist for additional support can help prevent sprains. An acute sprain can be treated with ice and NSAIDs. Other reported injuries include pectoralis major tendon rupture, triceps tendon rupture, glenohumeral joint dislocation, carpal tunnel syndrome, Achilles tendon rupture, and patellar joint dislocation [24].

Pectoralis major tendon and triceps tendon rupture can both be induced by the forceful actions of arm flexion and elbow extension during putting. These two injuries are discussed in greater detail in the discus and javelin sections, respectively. Both of these injuries are major injuries and require surgical consideration.

Anterior glenohumeral joint dislocations have been reported and are likely the result of the arm being in a vulnerable abducted, externally rotated position while forcefully pushing against the weighted shot. The athlete generally reports feeling the shoulder "pop out." On exam the prominence of the humeral head and a depression below the acromion can be appreciated. The examiner can also identify a "sulcus sign" which is created by the humeral head vacating the glenoid fossa, creating a sulcus. Manual reduction should be performed to relocate the humeral head. Ideally X-rays should be performed prior to reduction to detect any associated fractures, but in the field this generally is not practical. It is imperative, however, to obtain postreduction films to assess for any associated fracture. The athlete usually reports relief of pain following reduction. A first-time dislocation is traditionally treated with immobilization and rehabilitation to improve stability, but young overhead athletes have a relatively high recurrence rate, so surgical repair can be considered even following a first-time dislocation in this population [39].

Carpal tunnel syndrome is a repetitive use injury that shot putters are susceptible to. It can develop secondary to extreme wrist extension while holding the weighted shot, resulting in compression of the median nerve under the flexor retinaculum. Symptoms include pain, numbness, and paresthesias affecting the thumb, index, and middle fingers, and the radial half of the ring finger. Tinel's sign may be elicited by tapping over the median nerve proximal to the palm. Treatment includes splinting and NSAIDs in mild cases. Corticosteroid injections may also help reduce inflammation within the carpal tunnel. If conservative treatment fails, surgery can be pursued with release of the flexor retinaculum [40]. As a preventive measure, the putting wrist can be taped to limit extreme extension.

Achilles tendon rupture and patellar joint dislocation, as in the discus throw, are injuries that ambulatory athletes are susceptible to during the spinning or twisting actions of the "spin" and "glide" techniques. These injuries are unlikely to occur in seated athletes who are secured in either their wheelchair or a throwing chair. A more thorough description of the evaluation and management of Achilles tendon ruptures and patellar dislocations are in the discus injury subsection.

Boccia

Boccia is considered a low-risk sport from an injury perspective. Participants have athetosis, ataxia, and/or hypertonia. This disability will result in altered biomechanics when attempting to throw a ball. Research indicates that elite boccia athletes suffer fatigue, particularly involving the upper trapezius muscle, during prolonged play [41]. This study correlated fatigue with diminished performance, but there were no reported injuries. It is conceivable, however, that fatigue could increase the risk of overuse injuries. An additional study that examined the effects of wheelchair seat surface inclination during boccia throwing found that an anteriorly inclined seat provided greater postural stability (which is important for these athletes as they inherently have poor postural control) but resulted in a greater amount of elbow movement [42]. This increase in elbow movement may increase the risk of overuse injuries of the elbow. While boccia is in general a low-risk sport, the athletes participating have altered biomechanics which make the sport a strenuous activity.

Summary

The adaptive throwing sports and boccia are similar to their able-bodied equivalents. The injuries experienced in these sports are often secondary to the interplay between underlying disability and sport-specific activity. The available research suggests that the injury profiles for these adaptive sports are similar to that of the same able-bodied sports. The same research indicates that injury severity, in terms of days of competition or training lost, is similar between able-bodied and disabled sport [22, 43]. That being said, it cannot be emphasized enough how much more life-altering an upper extremity injury can be on a wheelchair athlete versus his or her able-bodied counterpart. The able-bodied thrower, for instance, may have to sit out from his or her sport, while the wheelchair thrower's activities of daily living will be affected. For this reason, more research should be conducted in the prevention and treatment of throwing-related injuries among adaptive athletes.

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25 Shooting Sports (Archery, Air Rifle, Trapshooting)

Yin-Ting Chen and Derick Mordus

Adaptive Archery

Introduction to the Sport and the Characteristics

Adaptive archery is one of the oldest adaptive sports, and its history is intimately associated with the dawn of the movement of adaptive sports. The first adaptive archery competition was organized by Dr. Ludwig Guttmann at Stoke Mandeville Hospital in Buckinghamshire, Britain, on 28 July 1948. The movement grew quickly, and by 1952, more than 130 international competitors entered the game, and the game eventually would become what is known today as the Paralympics [1]. Adaptive archery, or para archery, continues to enjoy great popularity in the adaptive sports community as it allows impaired athletes of all levels to participate in the sport at high level.

Adaptive archery is a sport of using a bow to propel arrows and emphasizes accuracy, concentration, and technique. Archers are assessed for their accuracy by hitting a target with the arrows from set distances. Archery demands strength and endurance in the shoulders, chest, and upper back. Muscles of core are instrumental for stabilizing the trunk and enable accurate aiming.

Y.-T. Chen, MD
Department of Rehabilitation, Walter Reed National Military Medical Center, US Army Medical Corps, Washington, DC, USA
e-mail: ychent@gmail.com

D. Mordus, MD (✉)
Department of Rehabilitation, Walter Reed National Military Medical Center, Bethesda, MD, USA
e-mail: drmordus@gmail.com

Sports Governance

The current governing body for adaptive archery is the World Archery Federation (WA, which is formerly known Fédération Internationale de Tir à l'Arc or FITA), in relation to the International Paralympic Committee (IPC). WA continues to be commonly referred to as FITA; particularly competitions following its rule are referred to as "FITA round." Adaptive archery competitions follow the WA/FITA rules. Presently 54 countries compete but the number continues to grow. Within the United States, the Wheelchair and Ambulatory Sports, USA, is another organization of adaptive sports that hosts adaptive archery events.

The Paralympics and the World Championships are the two major international competitions in adaptive archery. The Paralympics takes place on the same year as the Summer Olympics, while the World Championships are held on odd-numbered year. The usual format is a FITA round followed by an Olympic round, which is also referred to as elimination round. These events have both individual and team competitions.

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_25

Table 25.1 Classification system for Wheelchair and Ambulatory Sports [2]

W1	Tetraplegic archers in a wheelchair. All W1 archers are allowed to use a compound or a recurve bow, release aids, or any combination of the above. The equipment will be standard WA equipment rules with the exception of the addition of the release and compound bow
W2	Use a wheelchair for mobility but have good hand and arm function. W2 archers shoot recurve bows from wheelchairs, following FITA rules
Standing	Archers with a physical disability who shoot from a standing position and who are not classified as either W1 or W2. A stool or some sort of support may be used to provide stability, as long as the archers' feet are firmly planted on the ground. Standing archers shoot recurve bows, following FITA rules
Open compound	Archers who fit into one of the above categories but choose to shoot a compound bow following FITA rules. Open compound archers are allowed to use peep sight in the string, magnifying sight, mechanical release, and a maximum draw weight of 60 pounds

Table 25.2 Classification system for World Archery Federation [3]

ARW1 (also referred to as W1)	An archer with significant impairments, such as tetraplegia or comparable disability, affecting both upper extremity and lower extremities. Most ARW1 archers shoot compound bows, with draw weight limited at 45 pounds for men and 35 pounds for women
ARW2 (also referred to as W2)	An archer with impairment leading to significant limitation to their ability to use their lower extremities and trunk necessitates them to compete in the wheelchair. W2 archers shoot recurve bows following FITA rules
ARST (also referred to as ST)	An archer who is standing or shooting from a stool or a normal chair. An archer may be classified in ARST who require support due to poor balance caused by impairments such as limb deficiency, or impairments that affect their arms and trunk. ARST archers shoot recurve bows, following FITA rules
Open	Archers who classify into one of the above categories but choose to shoot a compound bow following FITA rules. FITA rules allow peep sight in the string, magnifying sight, mechanical release, and maximum draw weight of 60 pounds

Classification System

Each of the main archery governing bodies has their own classification system, and there is some variance between these organizations. The classifications span multiple disability groups, the male and female genders, as well as seated and standing competitors.

The various classification systems from the Wheelchair and Ambulatory Sports (Table 25.1), the US Paralympic Archery (Table 25.2), and the World Archery Federation are included.

Wheelchair and Ambulatory Sports, USA

There are three basic classes for men and women (Table 25.1) [2]. They include seated and standing competitors, as well as provision for equipment usage with either a recurve or compound bow.

US Paralympic Archery

The impairments and disability groups allowed under the US Paralympic classifications include amputation, spinal cord injury, wheelchair user, traumatic brain injury, cerebral palsy, and stroke. At present, the disability groups for visual impairment and intellectual impairment are not sanctioned. The classification for athletes competing in the US Paralympic archery competition is classified under the US Paralympic national classification strategy [3]. The classifications are:

World Archery Federation

Unlike the Paralympics, the World Archery Federation (WA) sanctions the visually impaired class. An athlete is classified as visually impaired if he or she has any damage to any part of the vision system, which includes structures within the eye as well as the neurological visual pathways [4]. There are three classes: VI1, VI2, and VI3. These classes must be determined by classifiers certified in determining visual impairment. The main difference in competition between the VI classes is that VI1 athletes are required to wear blindfolds when shooting, while the VI2 and VI3 athletes are not required to wear blindfolds. The remaining classifications are similar to the US Paralympics (Table 25.2) [3].

Rule

The basic tenant of all archery competition is the ability for each archer to shoot arrows accurately at a target. The targets used in archery competitions are standardized among the governing bodies; the targets are marked with ten concentric rings; the value increases progressively moving from the larger, outer rings to the central, smaller rings. The center is worth ten points, with the outermost ring worth one point. The formats of the competitions differ significantly between each governing body and they will be discussed individually.

Wheelchair and Ambulatory Sports, USA

Archery competition sanctioned by the Wheelchair and Ambulatory Sports, USA (WAS, USA), follows the FITA rules. A FITA round is 4 distances with 36 arrows shot at 90, 70, 50, and 30 m for men and 70, 60, 50, and 30 m for both women and W1 shooters. 122 cm targets are used for the two longest distances, and 80 cm targets are used in the two shorter distances. FITA rounds will be shot over a period of two consecutive days at National Wheelchair Games.

There is also junior division level of competition in WAS, USA. Archers in the junior divisions compete with each other based on gender, class, type of equipment, and age. The W1, W2, and standing classifications used in adults are also used in junior athletes. The type of equipment is determined by the bow and depends on whether the athlete utilizes either a recurve or compound bow. Lastly, the young athletes are categorized based on their age: yeoman (7 through 9), bowmen (9 through 12), cub (12 through 14), cadet (14 through 17), junior (17 through 21), and young adult (21 through 22). The distance of the target increases progressively from the yeoman to young adult category.

Paralympics

There are eight competitions for individual competitors: men's individual compound open, men's individual compound W1, men's individual recurve, men's individual recurve W1/W2, men's individual recurve standing, women's individual compound open, women's individual recurve W1/W2, and women's individual recurve standing. Each archer shoots 72 arrows from a distance of 70 m at a target of 122 cm. The highest possible score is 720.

In the individual events, all 64 competitors enter the competition at the first round, the round of 64. The draw is seeded according to the result of the ranking round, so the highest seed shoots against the lowest seed in the first round. Each match is the best-of-five sets, with each archer shooting three arrows per set. The winner of each set received two points; each archer received one point if the set is a tie. If at the end of five sets the score was tied at 5–5, a single arrow shoot-off is used to determine the winner.

In addition to the individual events, there are also two team events: men's team recurve and women's team recurve. Typically, 12 teams would compete in the team events. The top four seeded teams from the ranking round received a bye to the quarterfinal, while the 5th–12th seeded teams competed for the remaining four places in the quarterfinals. Each match consists of 24 arrows from each team (eight from each team member), and the team with the highest score progresses to the next round. In the event of scores being tied, a three-arrow shoot-off is used as tie breaker.

Equipment

Archery is a sport defined by its fundamental equipment: the bow and arrows. The components of a bow include a handle (grip), riser (or the handle) with two flexible limbs each ending in a tip with a string nock, and connected by a bowstring in between. Compound bow, which is a type of bow that uses a system of pulleys or cams to maximize mechanical energy in the draw, is also permitted to use in competition, as long as the peak draw weight does not exceed 60 pounds and the pressure of the adjustable arrow rest is not placed further back than 6 cm from the throat of the handle.

The arrow used in competition is anything that consists of a shaft with a tip (point), nocks, and fletching. Cresting is also allowed. The maximum diameter of the shaft is 9.3 mm not including the arrow wrap.

Other permitted items include the arrow rest, draw check indicator, bow sight, stabilizer, and torque compensator provided that they are not electrical components. Visual aids such as telescope, field glass, prescription spectacles, and sunglasses are permitted. Various protective equipment are permitted under the World Archery Federation rules, including arm guard, chest protector, bow sling, belt or ground quiver, finger stalls, gloves, and shooting tabs/tape.

Adaptive Equipment

Only minimal adaptive equipment may be necessary to enable participation in adaptive archery by an athlete with a disability. For individuals with lower extremity impairment, it may only require a stand or a stool to sit on for support. Wheelchairs may only require minimal modification such as removing the armrest on the bow arm; additional equipment such as shooting rest can be mounted on the wheelchair to improve bow stability. A tripod can serve the same function if no suitable device can be attached to the wheelchair.

For individuals with upper extremity impairment, more creative adaptive equipment may be required. There are a variety of compensatory strategies and devices for those with weakness in the arrow arm. A release aid, or a mechanical release, is a device used to help fire the arrow by reducing the torque required to hold the bowstring. Mechanical release is allowed in both adaptive and nonadaptive competitions. A mouth tab can allow shooter with only one upper extremity to draw the arrow with the mouth while using the intact arm as the bow arm. An electronic cocking device is another option for those with significant arrow arm impairment. Certain competitions also allow archers to have another person assist with nocking (may want to define this term for the reader) the arrow onto the bow. For individuals with bow arm impairment, it may only require simple modification such as a universal cuff or bandaging the bow to the hand to achieve a secure grip.

Common Injuries in Adaptive Archery

The literature on injuries associated with adaptive archery is scant, but extrapolation from nonadaptive archery suggests that it is a generally safe sport [5]. The data from 2012 London Summer Olympics Game showed that archery was one of the safest sports [6]. The most common pain suffered by archers is shoulder pain caused by rotator cuff tendinitis or tendinopathies [7], followed by injuries to the hand, forearm, elbow [8], fingers [9], and thumb [10]. Minor injuries in archery are generally associated with skin abrasion on the wrist from being struck by the bowstring after release of the arrow or abrasion on the fingers due to improper release technique. These can be prevented with proper protective equipment such as wrist guards, gloves, or release aids.

Shoulder injuries are frequently the sequelae of overuse, or improper techniques such as jerky draw, or poor equipment adaptation such as using bows with too high of pull weight. Rotator cuff pathology may lead to pain inhibition of the shoulder girdle muscles and lead to secondary shoulder impingement syndrome. Minor shoulder pain can be treated with over-the-counter oral analgesics and relative rest. Physical therapy should focus on rotator cuff rehabilitation and scapular reeducation. Improvement in proper archery techniques to optimize the biomechanics will improve both pain and shooting accuracy.

An uncommon injury associated with damaged equipment is the shattering of an arrow shaft during release, which can lead to severe penetrating injury to the archer [11]. A damaged arrow shaft can be undetectable visually but may fracture or shatter, as it no longer has the mechanical integrity to withstand the compressive force at the moment of release. Archers are always advised to test their arrows prior to shooting by flexing them.

Parashooting

Introduction to the Sport and the Characteristics

Parashooting was first introduced to international competition in Toronto during the 1976 Paralympic Games. Paralympic shooting initially started as a disability-orientated classification system and moved toward the functional classification system currently in use. As a result, the number of classes has been reduced from five classes with separate events at the Seoul 1988 Paralympic Games to three classes with integrated events since the Atlanta 1996 Paralympics. At the London 2012 Games, 140 athletes took part in 12 medal events [12].

Sports Governance

The primary governing body for sport shooting is the International Paralympic Committee (IPC), which uses modified rules of the International Shooting Sport Federation (ISSF), the main organization for Olympic shooting. These modified rules were developed to account for difference between shooting for able-bodied and shooting for persons with impairment.

Competition

The sport of shooting is a challenge of accuracy, precision, and control that comprises the use of pistols or rifles to fire shots at a stationary target. Advantages in the sport come from techniques to increase stability such as breathing and heart rate timing. The sport requires a high level of focus and concentration to deliver numerous shots on target.

Competition is set up such that the competitors fire a series of shots toward a target's bull's-eye. The target consists of ten concentric rings with a score of 1–10, with the value increasing progressively toward the center. In final rounds and in some qualification rounds, each ring is further delineated into smaller concentric rings associated with a decimal scoring system with a top score of 10.9. Athletes compete in events from distances of 10 m, 25 m, and 50 m in men's, women's, and mixed competitions. There are 12 total Paralympic events: 6 mixed, 3 women only, and 3 men only. Shooting competitions are divided into rifle and pistol competitions. The rules depend on the gun used (air or .22 caliber), distance, target, shooting position, number of shots, and time limit. Competitors accumulate points for the value of their shots. The top eight scorers in qualifying rounds advance to the final round where scores are reset and the top two competitors are awarded with gold and silver medals.

IPC shooting has three levels of competition. Level 3 includes the Paralympic Games and the World and Regional Championships and is the highest level of competition. World Cup events are considered Level 2. Level 1 events are those competitions approved by the IPC and the National Paralympic Committee (NPC). The Level 3 events occur on a 4-year cycle with Regional Championships on years 1 and 3, World Championships on year 2, and the Paralympic Games on year 4.

Disability Groups/Classification System

Paralympic shooting is open to athletes who have a physical impairment leading to reduced function in the lower and/or upper limb(s). IPC shooting employs a functional classification system where athletes compete in sport classes based on their functional ability, rather than impairment type as was done in the past.

Impairments which meet the IPC eligibility for shooting are in Table 25.3 [13].

The IPC has inclusive details of the minimum impairment to meet eligibility for each type of impairment in its IPC shooting classification rules and regulations publication.

Athletes with physical impairments are further delineated into three different sport classes as defined by the IPC in Table 25.4 [13].

SH1 class includes athletes with lower limb impairments that require many competitors to

Table 25.3 Impairment eligible for shooting under IPC and their definitions [13]

Hypertonia	Due to injury, disease, or other condition which damage the central nervous system
Ataxia	I.e., due to cerebral palsy or multiple sclerosis
Athetosis	I.e., due to cerebral palsy or brain injury
Impaired muscle power	Muscles of a limb or lower half of body from paraplegia, poliomyelitis, spina bifida, or other conditions
Impaired passive range of motion	
Limb deficiency	Total or partial absence of bones and/or joints from trauma, illness, or congenital causes

Table 25.4 Impairment classification under IPC for shooting sports [13]

SH1 (pistol)	Athletes with upper and/or lower limb impairment for competition in pistol events
SH1 (rifle)	Athletes with lower limb impairment for competition in rifle events
SH2	Rifle events only. For athletes with upper limb impairment which requires a shooting stand to support the rifle. May or may not be in combination with lower limb impairment

compete while sitting, either in a wheelchair or on a stool. It also includes athletes with either no upper limb impairments or an upper limb impairment that does not prevent the athlete from supporting the weight of the rifle or pistol (non-shooting arm in the case of pistol). Additionally, SH1 pistol classification may use a loading device. This is allowed if the athlete is unable to load the pistol safely and is determined on a case-by-case basis during classification. This also applies to SH2 classification with regard to a loading assistant if the athlete is unable to safely load the rifle.

SH2 class includes athletes who in addition to lower limb impairments have upper limb impairment that prevents them from supporting the weight of the rifle alone. These athletes compete only in rifle events and use a spring-mounted stand to support the weight of the rifle. Some athletes also require an assistant to load the rifle for them. SH2-classified shooters may also qualify for the use of a weak or strong spring for rifle support with the stronger spring associated with larger impairment. This is based on the shooting arm strength for forearm pronation/supination, wrist flexion, wrist extension, and thumb and finger opposition.

These classes are further subdivided into A, B, and C which are based on trunk stability. There are five screening tests used to characterize the athlete's trunk stability. An "A" classification indicates the athlete is able to return to center of gravity after performing all five tests. This means the athlete is not allowed to use any sitting support during competition. A "B" classification indicates moderate instability and allows the shooter to use a backrest which exposes 60% of their back measured from C7 to their sitting surface. Classification "C" indicates an inability complete any of four of the five stability tests. Shooters in class C are allowed to use a backrest that does not rise above 10 cm below their armpits while competing.

All classifications are allowed to use trigger adaptations if the shooter is unable to use a trigger inside the dimensions of the trigger guard. This will be determined during classification assessment on an individual basis. Currently there is no designation for blind athletes. Once it was referred to as SH3, but this classification is not currently compliant with the Classification Code or agreed upon by the IPC.

Rules

Below is a list of the events recognized by IPC shooting. Only the bolded events occur at the Paralympic Games (Table 25.5) [14].

Shooting Positions

Rifle

Kneeling: Depending on handedness, athletes place their ipsilateral knee and toe and contralateral foot on the ground according to ISSF rules [14]. Prostheses or stools up to maximum of 35 cm height are allowed by SH1A athletes. Additionally, only one elbow may contact the

Table 25.5 Shooting events recognized in IPC

Event	Discipline	Gender	Class	Shots	Time electronic targets	Time target carriers and pit-operated competitions
R1	10 m air rifle standing	Men	SH1	60	1:15	1:30
R2	10 m air rifle standing	Women	SH1	40	0:50	1:00
R3	10 m air rifle prone	Mixed	SH1	60	0:50	1:00
R4	10 m air rifle standing	Mixed	SH2	60	1:15	1:30
R5	10 m air rifle prone	Mixed	SH2	60	1:00	1:10
R6	50 m rifle 3 prone	Mixed	SH1	60	0:50	1:00
R7	50 m rifle 3 position	Men	SH1	40 kneeling 40 prone 40 standing	2:45	3:15
R8	50 m rifle 3 position	Women	SH1	20 kneeling 20 prone 20 standing	1:45	2:00
R9	50 m rifle 3 prone	Mixed	SH2	60	1:00	1:10
FTR1	Falling targets rifle	Mixed	SH1			
FTR2	Falling targets rifle	Mixed	SH2			
P1	10 m air pistol	Men	SH1	60	1:15	1:30
P2	10 m air pistol	Women	SH1	40	0:50	1:00
P3	25 m air pistol	Mixed	SH1	60		
P4	50 m air pistol	Mixed	SH1	60	1:30	1:45
P5	10 m air pistol standard	Mixed	SH1	40		
FTP	Falling targets pistol	Mixed	SH1			

Times unit in hours [14]

board or table with the rest of body clear as to prevent increasing the stability of the shooter and preventing unfair advantage.

Prone: This position involves lying front down with the highest ground contact and most stability. For 50 m rifle prone, athletes may choose to shoot either prone or with the use of a shooting chair and table. In 10 m air rifle prone competition, the athletes are required to use a chair and table. SH1 athletes must have both elbows touching the table, with a forearm angle greater than 30. Prosthetic devices without a fixed elbow and that do not grip the rifle are allowed. SH2 athletes are required to place both elbows on the table (impairment dependent) without the upper arms touching. Slings are not allowed during competition.

Standing: Athletes with a trunk function score of "A" may stand if capable without artificial support (with exception of orthoses or prostheses). High stool shooters must be able remove their feet from the floor with losing balance. SH1 athletes must support the rifle with their arms only, and no part of their arms may contact a shooting chair or their lap. SH2 athletes must deshoulder the rifle between shots. The use of a loading assistant is allowed for SH2 athletes. They are not allowed to speak or signal during competition but may adjust sights as requested.

Pistol: Athletes with "A" trunk function score may compete while standing but must do so without support as in the rifle section above. Arms and sideboards of shooting chairs are to be removed from those requiring their use. The athlete's shooting hand must be in contact with their shooting chair as to avoid an unfair advantage. There are additional rules to allow a competitor who is unable to approach the loading bench or is compromised while doing so and may use an additional table that does not grant an unfair advantage.

Adaptive Equipment

The adaptive equipment is not supposed to give any unfair advantage to any competitor. Any equipment that provides a discerned advantage is not allowed and is prohibited. Equipment and apparel must follow the ISSF and IPC guidelines.

Athletes use .22 caliber rifles and air guns (pneumatic, CO2 gas, or spring). For 10 m events held with an air rifle or air pistol, bullets with a diameter of 4.5 mm are used. For 25 m pistol events and 50 m pistol and rifle events, 5.6 mm bullets are used.

The standard target is a cardboard square with concentric white and black rings around a black center ring (or bull's-eye). For the Paralympic Games, five different targets are used depending on the type of gun. These targets are electronic for increased accuracy. Some targets are further delineated by smaller rings for more accurate and competitive scoring.

IPC-Specific Equipment

A shooting chair is defined as any object the athlete sits upon to shoot including wheelchairs, stools, chairs, seats, and high stools, with the height specified as being equal or higher than athlete's mid-thigh height. Most shooting chairs require removable armrests, sideboards, and/or tables as many competitions do not allow these adaptations.

Strapping is not allowed to give increased stability to an athlete, and therefore athletes may not touch the straps while competing. When utilized, the straps are to be 5 cm less in width. There may only be one strap that is placed below the knee and strapped to the shooting chair that is allowed. An above-knee strap strapping the athlete's legs together is allowed but may not be attached to the chair. However, bilateral transfemoral amputees are allowed to strap across their residual limbs to the shooting chair.

Shooting tables are to be no larger than 90 cm in diameter and may be free standing or attached to their chair. They can be composed of multiple individual tables as long as they fall within the maximum size and must also be within 5° of the angle of the floor. Upholstered tables are allowed (maximum thickness 2 cm without hollows).

A SH2 rifle support stand is designed to support the weight of the rifle. The stand will have either a strong or weak spring based on the athlete's subclass of "A" or "B." The minimum flexibility of the weak spring is 35 mm and of the strong 25 mm. They are typically fixed on a tripod or table.

Trigger adaptations are allowed based on classification of the athlete. These include any adaptation required by the athletes, which include any area outside the standard dimensions of the trigger guard.

Other IPC-specific equipment includes prostheses, compensating blocks, and loading devices (pistol). Each piece of equipment must be approved by the IPC during the technical review and must not offer an unfair advantage to the athlete.

Trapshooting

Introduction

Trapshooting is one of the three major disciplines of competitive clay pigeon shooting; the other disciplines are skeet shooting and sporting clays. All of these sports were originally developed as a practice method for bird hunters. In trapshooting, at the command issued by the stationary shooter, classically "pull!", a target is launched from a trap house or machine away from the stationary shooter. The target is usually a 4–1/4 in. clay disk, propelling through the air at a speed of 42 mph, simulating the flight path of a bird fleeing a hunter. The target is considered hit as long as the bullet damages the target in anyway.

Like other shooting sports, trapshooting is gaining popularity in the adaptive sports world due to the ease of access and participation for participants of all levels. While trapshooting is gaining popularity internationally and has been an Olympic event since 1990, it has not become an official event in Paralympics.

Classification

Currently, because it has not been declared an official sport, there are no limiting rules of eligibility in adaptive trapshooting. However, only the physical impairment classes are sanctioned in Paralympics for parashooting sports, with intellectual impairment and visual impairment classes being disallowed. There are two factors in the classification of the shooter: the cumulative record and the ability. The two governing bodies for American trapshooting, the Amateur Trapshooting Association (ATA) and the Pacific International Trapshooting Association (PITA), have developed systems to class experienced shooters based on these two factors. ATA classification goes from AA at the highest to D or E at the lowest, while the PITA rating goes from AAA at the highest (six classes) to D.

In addition to the traditional rules, the Paralyzed Veterans of America (PVA), the leading organization for adaptive trapshooting, also utilizes a handicap review system to appropriately adjust the handicap according to the shooter's impairment. The shooter can initiate the request for handicap review, which will be conducted during the meeting of the tournament directors of PVA National Shooting Sports Circuit 19 [15]. Adaptive trapshooting is currently not an event in Paralympics, and there are no large international governing bodies, but the International Shooting Sport Federation (ISSF) has been trying to start a movement to bring adaptive trapshooting into the Paralympics [16].

Rules

There are three forms of competitions in the ATA rule: singles, handicap, and doubles. Singles is shot from 16 yard line for 100 targets. In handicap events, shooters fire at varying distances; less advanced shooters are given longer distances due to less movement and slower reaction time required during tracking and aiming, therefore lowering the degree of difficulty. In double events, two targets are released simultaneously, shot from 16 yard line. Most doubles events release 100 targets in 50 pairs.

The PVA tournament rules follow the ATA rules, with modifications [17]. Shooters are classified by the tournament director using the latest "known ability" data available including, but not limited to, PVA trapshooting results and averages and ATA or PITA averages. A new shooter who has never shot in official trapshooting events will be classified as a novice shooter and will start in class D in both singles and doubles with a handicap of 20 yard line for male and 19 yard line for female. Each of the tournaments will consist of singles for 100 targets, handicap for 100 targets, and doubles for 50 pair targets. Only these 300 clays will be used for final score totals.

Adaptive Equipment

The quintessential equipment of trapshooting is the shotgun. Generally trapshooting is conducted with 12 gauge shotguns. The shotguns may be single or double barrels, and shooters may have multiple shotguns, each tailored to a specific event. Both general and specialized shotgun built specifically for trapshooting can be used. Semiautomatic shotguns are popular as they can be used for single, handicap, and double events. Common accessories used in trapshooting include vest or pouches to hold cartridges and shells. The use of hearing and eye protections is generally mandatory.

There are no specific rules regarding the adaptive equipment. For shooters with lower extremity impairment, a bench, stool, or wheelchair may be all the necessary adaptive equipment. Shooters with upper extremity impairments may use a trap suspension system, depending on the impairment. An overhead trapeze and cable systems can be used to help suspend the shotgun for the shooter for those with coordination or weakness issues. For shooters with unilateral impairment such as hemiplegia, a tripod can be useful to stabilize the shotgun on the weak side, while the unimpaired hand functions as the trigger hand. Specialized prosthesis can be constructed to improve handling and accommodation of the shotgun. While there are no commercially available systems, it can be constructed easily.

Common Injuries

As long as the safety rule of firearm handling is followed, like other shooting sports, trapshooting is a very safe sport with minimal injuries.

These rules include the following: (1) always point the firearm downrange and not in the direction of anyone else, (2) keep fingers off the trigger until ready to fire, (3) never move from a station with a loaded gun, (4) follow all instructions from range safety officer, and (5) use eye and hearing protection at all times. Similar to other shooting sports, the most of the injuries associated with trapshooting is hearing damage, which can be limited with proper hearing protection.

Summary

The adaptive shooting sports offer excellent opportunities for participation for individuals with disabilities. With often only minimal modification and adaptive equipment, persons with disability can compete at high level with able-bodied individuals. The varieties in the sports (archery, pistol, rifle, trapshooting) and the event format offer disabled shooters tremendous freedom for exploration and opportunities for progression in skill. The injury patterns for adaptive shooting sports are minor and generally avoidable with proper equipment, technique, and event administration. There are many governing bodies for each adaptive shooting sport, each with its own classification rules and event formats, but there is also a huge body of resources to help disabled shooters to get started.

Resources

- World Archery Federation: http://www.worldarchery.org/
- *Wheelchair and Ambulatory Sports, USA*: http://www.wasusa.org/
- *US Paralympics Archery*: http://www.teamusa.org/Home/US%20Paralympics/Sports/Archery.aspx
- International Shooting Sport Federation: http://www.issf-sports.org/
- Amatuer Trapshooting Association: www.shootata.com
- Pacific International Trapshooting Association: www.shootpita.com
- Paralyzed Veterans of America: www.pva.org

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Weight Lifting in Adaptive Sport

26

Pegah Dehghan, Luis Guerrero, and Arthur Jason De Luigi

History of Adaptive Powerlifting Sport

Adaptive powerlifting became an official Paralympic sport when the bench press was launched in the Tokyo Paralympic Games in 1964. This inaugural event was exclusive to only male athletes with spinal cord injuries. The sport continued to limit participation and eligibility for competition to include only wheelchair-classified athlete until 1984. In the 1984 Paralympic Summer Games, the sport was open to other disability groups when athletes with cerebral palsy (CP) received permission to participate at the Games for the first time. During the 1984 Games, there were two separate competitions—one in Stoke Mandeville, UK, for wheelchair athletes with spinal cord injuries and the other in Long Island, NY, USA, for wheelchair and ambulatory athletes with CP and limb deficiency due to amputation or congenital deformity. The latter competition in the USA has since been referenced and became known as "the last minute game." The competition for CP weight lifter and limb deficiency was the last event of the games and was held in a different venue than the Summer Olympic Games.

By 1988 in Seoul, the powerlifting returned to Paralympics for men. In 1992, it was decided to feature powerlifting as opposed to weight lifting in the Paralympics. This decision resulted in appearance of athletes from 25 countries in Barcelona.

Paralympic level competition was first opened to females for the 2000 Summer Games and showcased the first female competed in Paralympic powerlifting. From there, the sport has steadily increased in popularity and participation. During the London Paralympic Summer Games in 2012, 200 athletes competed in 20 medal events. The sport is ruled by the International Paralympic Committee (IPC) and incorporates rules similar to those of powerlifting competitions for able-bodied athletes [1–3].

Classification

Powerlifting classifications are regulated by IPC Powerlifting. The classification system is designed to create fair competition for powerlifters with a disability. It is used to determine who is eligible for competition in the sports event, as well as within which weight class. The classification system allows adaptive powerlifters with

P. Dehghan, MD (✉)
Kennedy Krieger Institute, Baltimore, MD, USA
e-mail: peggydehghan@yahoo.com

L. Guerrero, MD
MedStar Health, Washington, DC, USA
e-mail: drlagmd@msn.com

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine,
Washington, DC, USA
e-mail: ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_26

different impairments to compete for the same medals. The goals of classifications are to permit weight lifters with various disabilities to compete against each other and to minimize the effect of eligible impairments on the games' result.

For a powerlifter to be eligible for competition, they must have an eligible disability, which complies with the minimal disability criteria set by IPC Powerlifting. The IPC creates a classification panel and trains classifiers to evaluate the athlete's impairment to allow for appropriate classification. If a classification panel ascertains that an athlete is not eligible to compete, the athlete will be allocated "Sport Class Not Eligible" (NE). In this case the competitor may appeal and will be required to undergo a second athletic evaluation by a second separate classification panel to declare eligibility prior to competition. During the appeal process, the athlete will not be allowed to compete. If a second classification panel confirms the previous evaluation, the athlete will not be permitted to participate at any future competitions. Although the competitor is not eligible to compete within the sport of IPC Powerlifting, he or she will be able to participate in other para-sports, subject to their rules on classification [2].

Since 1983, weight lifters with impairments due to stroke, epilepsy, CP, or stable brain injury have been qualified to compete following medical clearance [1, 2]. According to the classification, people with spina bifida are not classified unless they have locomotor dysfunction [1, 2].

In 2012, powerlifting was opened to athletes with any lower extremity impairments that avert them from participating in able-bodied contest. This change allowed athletes with lower limb deficiency due to amputation or congenital malformations and lifters with CP or spinal cord injuries to be able to compete in these Paralympic events [1, 2]. According to the International Sports Organization for the Disabled, all athletes with muscular dystrophy and multiple sclerosis can be classified for the games of Les Autres [3].

In regard to upper extremity function, eligible adaptive powerlifters must have both arms and be able to extend their arms within 20° of full extension during a lift [1].

Rules

Paralympic powerlifting is a competition, which focuses on the bench press. The classification is divided into weight classes and is based on bodyweight alone. The competitors are weighed 2 h before their games. During the event, a weighted bar is placed on a rack with two posts. The weight lifter is lying flat on a specially designed bench underneath the weighted bar [2, 3].

The competitors may attempt three lifts during the competition. They start with the lowest weight and gradually increase the weight each time by at least 1 kg. A fourth attempt is permitted for a record, but it would not count in the final result of the competition [3].

The athletes may lift the bar after the chief referee commands that the lifter may "start." The lifters must bring down the bar to their chests, keep it motionless, and then follow by bringing the bar upward evenly to arm's length. In this state both arms should be locked concurrently until the chief referee commands, "rack." The three judges will indicate a successful or unsuccessful lift by turning on a white or red light. The lifter has 2 min from announcing his or her name, country, and the weight until initiating the attempts. They should leave the platform within 30 s after completing their lift.

The athlete who gets the highest score within his or her category during the competition takes the gold medal. If the athletes are tied up, the winner is the lightest lifter who lifted the heaviest weight. If both athletes have an identical body weight, a reweigh is done [1, 3].

If two athletes break the same record during the competition, the athlete who first lifted the new weight would be the record holder. The record will only be valid if it exceeds the previous record by 500 g [3].

Adaptive Powerlifting Equipments and Apparels

The powerlifter should look respectful and tidy. The lifter's dress consists of:

1. Tight fitting Lycra-type material suit.
2. Cotton or polyester T-shirt: It must be worn under the suit.
3. Shoes: Lifter should appear with shoes unless in specific situation.
4. Lather, vinyl or other non-stretching belts.
5. Woven elastic bandage and wrist wrap.

The referees must write all items on the official sheet (see Table 26.1). After the athlete passes the inspection, the lifter presents on platform measuring between 2.5 × 2.5 m and 4.0 × 4.0 m in front of the standard and straight bar. The distance between weight lifting collars should be minimum of 1310 mm and maximum of 1320 mm. The bar should be loaded with disk (see Table 26.1) [3].

Table 26.1 Required Apparel and Equipments

(A) Apparel		
1	Suit	The pants must be at least knee length
2	T-shirt	It should have sleeves (not longer than elbow)
3	Shoes	All lifter must wear them unless in specific situation, which were approved by doctor and classifier
4	Belt	It should be made of non-stretch materials. It must be worn over the suits
5	Bandage and wrist wrap	It can be used only if it is made of specific materials and size. Rubbers are forbidden
(B) Equipment		
1	Platform	It must be flat and firm
2	Bar	It cannot be changed during the events unless it is broken or damaged
3	Collars	It weighs 2.5 kg each
4	Disks	The heavier disks must be placed inner
5	Bench	It has specific length, width, height, and stands
6	Lights	Two colors lights are used in the event so the referees could acknowledge their decisions

Notes: The lifters are not allowed to use lubricant such as oil. They are permitted to use powder. The athlete's name should be placed on all of his or her cloths and equipments [3]

Adaptive Powerlifting Injuries

The weight lifting injuries could be caused by many different etiologies including poor technique, carelessness, equipment problems, and fatigue. One study has shown that the typical injuries in elite lifters are primarily overuse injuries instead of being traumatic [4]. The athletes who lift larger weight are more prone to injury than others. In general, the chance of injuries particularly neck and back injuries directly correlates with the weight. The most common adaptive powerlifting injuries are listed in Table 26.2 and will be discussed in further details [4, 5].

Shoulder Injuries

Knowledge of the anatomy and normal range of motion of shoulder is crucial in making the proper diagnosis and treatment (see Table 26.3). In this section, the anatomy of shoulder would be explained briefly.

Glenohumeral joint (ball and socket) and acromioclavicular joint form the shoulder joint. In addition to these joints, sternoclavicular joint should be examined in the shoulder injury. The two most important shoulder muscle groups are as follows:

1. *Rotator cuff muscles*: supraspinatus, infraspinatus, teres minor, and subscapularis
2. *Scapular stabilizers muscles*: trapezius, serratus anterior, rhomboid major, rhomboid minor, and levator scapulae

Rotator Cuff Impingement and Tear

Rotator cuff impingement should be diagnosed clinically. It occurs when the tendons, especially supraspinatus, are impinged as they cross the subacromial space and beneath the acromion. This impingement leads to inflammation, which in turn increases the likelihood of tendon tear. This injury is very common in all athletes, particularly swimmer, lifters, adaptive athletes,

Table 26.2 Adaptive powerlifting injuries

	Shoulder	Elbow and wrist	Spine and back	Lower extremities
1	Rotator cuff impingement and tear	Olecranon bursitis	Neck injury	Knee injuries particularly patellar tendonitis
2	Glenohumeral arthritis	Radiocarpal joint strain	Low back pain	Ankle joint injury
3	Distal clavicle osteolysis		Strained ligament	
4	Rupture of pectoralis major		Disk herniation	

Table 26.3 Shoulder movement, normal range of motion (ROM), and involved muscles [6]

Movement	ROM	Muscles
Flexion	0–180°	Biceps brachii, anterior deltoid, pectoralis major, coracobrachialis
Extension	0–60°	Posterior deltoid, pectoralis major, latissimus dorsi, triceps, teres major
Abduction	0–180°[a]	Middle deltoid, supraspinatus
Adduction	0–60°	Pectoralis major, latissimus dorsi, teres major, coracobrachialis, infraspinatus, triceps, deltoid
Internal rotation	0–90°[b]	Subscapularis, anterior deltoid, pectoralis major, latissimus dorsi, teres major
External rotation	0–90°[b]	Infraspinatus, supraspinatus, teres minor, posterior deltoid

[a]If the thumb pointed to the ground, the shoulder abduction decreases to 120°
[b]In order to properly measure shoulder internal and external rotation, shoulder must be abducted

Table 26.4 Neer stages of rotator cuff injury

Stages	
I	Edema and inflammation within the muscles/tendon
II	Rotator cuff tendonitis or fibrosis stage
III	Partial or complete tear of the muscles. It occurred by narrowing of the gap between the anterior edge of acromion and humeral head secondary to inflammation of the rotator cuff tendon, scapulothoracic dyskinesia, glenohumeral laxity, or instability

and throwers. Neer divided rotator cuff injury and impingement into three stages (see Table 26.4) [7, 8].

Detection of rotator cuff impingement requires a good history and physical exam. In a classic presentation, the athlete complains of shoulder pain particularly with overhead movement. It is frequently associated with limited shoulder motion and occasionally weakness. The degree of weakness depends on the severity of pain and the extent of the inflammation or the possible tear. Additional symptoms associated with rotator cuff pathology include a clicking sound (with calcific tendinitis) and pain with lying on the affected shoulder. The physical exam may reveal limited range of motion accompanied with pain especially with shoulder abduction, extension, and external or internal rotation. Positive tests can include the Hawkins test, Neer's test, and resisted external rotation test (Empty Can) [8–10]. True rotator cuff weakness relies on the severity of damage to the muscle or tendon. Since these findings are often complex, imaging studies can be helpful. Outlet view X-rays are used to detect bone spurring on the front edge of the acromion. MRI and ultrasound reveal better soft information including rotator cuff inflammation, bursa, and partial or complete rotator cuff tears [10–12].

Initial treatment is usually nonsurgical. The athlete is recommended to modify exercises particularly overhead activities. Nonsteroidal anti-inflammatory medicines might be helpful for reducing pain and inflammation but are less effective if the injury is chronic in nature. Physical therapy should start as soon as possible. It must initially focus on enhancing range of motion and scapular stabilization techniques, then progress to rotator cuff strengthening. If these treatments fail, corticosteroid injections could be considered. Prolotherapy and platelet-rich plasma injections can be considered as potential options as well [7–9, 13].

When the patient does not respond to conservative management or in the case of a significant tear, surgical treatment may be recommended. However, additional consideration should be taken by the surgeon on how surgery would impact a wheelchair bound individual who use their upper extremities for mobility. Postoperatively, a shoulder sling would be placed to keep the arm in about 20–30° of abduction, which decreases tension of the repair. Initially it may start a passive range of motion and then progress to active motion with terminal stretching 6 weeks after surgery. Subsequently 10 weeks after the procedure, resistive exercises may be added. Recovery time might be as long as 4–6 months and in some cases it even takes 1 year [7–9, 12, 14].

Glenohumeral Arthritis

Glenohumeral arthritis can be divided into primary and secondary arthritis. Primary osteoarthritis affects the shoulder joint and usually in persons older than 60 years in the general population. The secondary osteoarthritis is subdivided into non-traumatic (inflammatory arthritis) and traumatic. Traumatic glenohumeral arthritis is commonly seen following fracture and chronic instability (dislocation arthropathy). It can also be found after significant rotator cuff tears are left untreated in athletes. In regard to adaptive sports, glenohumeral osteoarthritis is common in wheelchair athletes who are using their shoulders for primary locomotion [15, 16].

A thorough history should be taken and should include inquiries regarding episodes of trauma, recreational/sport/social activities, and prior medical and surgical treatments such as physical therapy, medications, and shoulder injections. The patient typically has complaints of pain/discomfort, clicking noises, decreased range of motions, feelings of catching, and instability [15, 17].

The physical examination should rule out pathology that could confound the examination and treatment outcomes in the shoulder including cervical spine or acromioclavicular joint injury. Restricted painful shoulder range of motion is commonly found. Typically, end range of motion pain is due to impingement, osteophytes, and capsular contracture. Impingement signs should be evaluated as well as evaluation of the biceps tendon. Radiographic studies such as anteroposterior X-ray in neutral rotation, scapular outlet, and an axillary view illustrate degree of glenohumeral arthritis [18, 19].

A Bernageau view can be performed to assess shoulder (see Fig. 26.1a, b).

These views document the humeral head location in glenoid fossa, presence of osteophytes, composition of bone, relative glenohumeral joint margin, and visualization of glenoid bone loss.

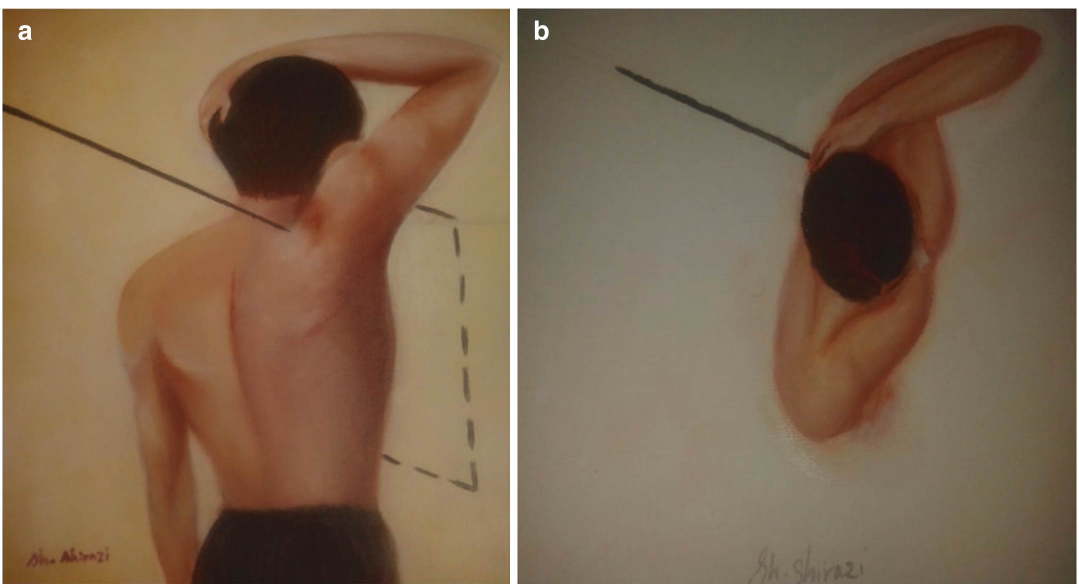

Fig. 26.1 (**a**, **b**) Bernageau view

CT arthrograms are obtained to evaluate glenoid bone stock, rotator cuff muscle, and tendon quality such as fatty infiltration. MRI is not typically a routine part of the diagnostic workup for this condition; however, it may be useful in the assessment of any concomitant pathologies [18, 19].

Conservative management includes oral or topical NSAIDs, physical therapy, and activity moderation for 6–12 weeks. After this initial trial, a course of corticosteroid injection could be utilized periodically to decrease pain and inflammation. Additionally, one may consider regenerative medicine and orthobiologic options such as platelet-rich plasma (PRP), bone marrow (BMC), or adipose-derived stem cells [15, 17]. If conservative management fails, surgical options can be considered. The procedure depends on the severity and mechanism of injury. Surgical options include arthroscopic debridement, partial shoulder replacement, total shoulder arthroplasty, and reverse shoulder arthroplasty [15, 17, 20].

Osteolysis of the Distal Clavicle

Non-traumatic osteolysis of the distal clavicle is a stress overload syndrome. It is predominantly observed in weight trainer that participates in bench pressing. Scavenius and Iversen's study compared 25 professional lifters with age-matched controls. The study revealed 28% of lifter had non-traumatic osteolysis of the distal clavicle in their imaging studies [21, 22].

Typically, the patient complains of gradually progressive acromioclavicular (AC) joint pain, with intermittent referral to deltoid or superior aspect of trapezius. Bench pressing, especially using weight greater than 200 pounds (>90 kg) aggravates the pain.

The Zanca view (AP X-ray of the AC joint with 10–15° cephalic tilt) shows subchondral bone loss with osteoporosis at distal clavicle accompanied with a subchondral cystic. Increasing acromioclavicular joint space presents in the late stage. A bone scan can be used to support the diagnosis since it assesses the biological activity at the clavicle. Osteolysis may show up as area of increased uptake in the bone scan [21, 22].

Initially conservative treatment includes anti-inflammatory medication, corticosteroid injections, and activity restriction particularly eliminating the provocative maneuvers can be beneficial. Unfortunately, competitive lifters need the weight training to sustain and improve strength in addition to their body mass. For this reason, some weight lifters might be unwilling to lower the level of their performance and prefer surgical interventions. The open and arthroscopic sugary includes distal clavicle resection [21–24].

Postoperative rehabilitation is critical and involves early passive shoulder movement and pendulum activity to avoid adhesive capsulitis. In the open surgery, deltoid is partially detached, and therefore, active movement of shoulder must be limited initially. However, after arthroscopic treatment, the athlete can start active motion within the first week [21, 24, 25].

Pectoralis Major Rupture

Rupture of the pectoralis major is rare. It often happens in men participating in sports such as weight lifting, rugby, or wrestling. The process of rupture is usually indirect and associated with significant tension, while the muscle is maximally contracted with the abduction and externally rotation of shoulder. The rupture is classified as partial or complete with the most common location is at the insertion to the humerus [26, 27].

Physical exam demonstrates ecchymosis and swelling at the chest, upper arm, and axilla associated with painful shoulder motion. After resolving the swelling, a palpable defect could be detected at the site of rupture. The shoulder adduction and internal rotation is weak. Weakness is observed with the arm adducted and internal rotated. It is hard to differentiate between complete and partial ruptures in the acute setting; therefore it may be necessary to repeat the physical exam once the swelling has resolved. MRI is helpful in the determining the degree of rupture and obtaining additional information [26–28].

The treatment depends on the degree and the location of the rupture. In partial ruptures of the muscle belly, conservative management is recommended. Initial treatment includes immobilization with a sling and application of cold therapy. The physical therapy could start on the second or third day. Initial therapy includes pendulum exercises, followed by gradual progressive shoulder range of motion activity. Muscle strengthening exercises must be avoided in the first 4 weeks. Light isotonic and isokinetic exercises are allowed by the fourth week. The recovery usually takes 6–8 weeks [28, 29].

Surgical treatment is preferred within the first 8 weeks after injury in the complete injury especially with an associated avulsion. Patient should wear a sling for a month postoperatively. However, gentle shoulder range of movement should start in the first week, followed by slow progressive isotonic exercises at 6 weeks with progress to strengthening and functional exercises by the first 3 months. Full range of motion is usually obtained by 6–8 weeks. The powerlifter typically progresses to unrestricted weight lifting by 6 months after the repair [28, 29].

Olecranon Bursitis

The olecranon bursa is a synovium-lined sac filled with lubricant fluid. Due to its superficial location, it is susceptible to trauma and inflammation. The diagnosis is usually made by history and physical exam. Imaging studies are only required to rule out another diagnosis. In the physical exam, a fluid collection might be found. The range of motion of the elbow is often pain free except terminal elbow flexion [30, 31].

Olecranon bursitis typically responds well to conservative management and the treatment is usually nonsurgical. If there is fluid collection, it should be aspirated and compression dressing should be applied. It is critical to rule out infection in olecranon bursitis and start empirical antibiotic after fluid aspiration. After ruling out infection, in some cases corticosteroid could be injected into the fluid sac after aspiration. If there is no fluid, patient is recommended to take anti-inflammatory medications for 7 days. Finally, surgical intervention such as bursectomy may be considered if the conservative treatment fails. Subsequently, elbow splint in 45–60° of flexion should be placed. Early range of motion is allowed to prevent stiffness [31–33].

Athlete can start exercises in 4 weeks with 6 weeks of contact restriction. The patient may wear soft elbow pads until tenderness resolves [31, 33].

Low Back Pain

Extension or flexion of the paraspinal muscles against resistance during weight lifting and bodybuilding may result in a number of injuries, most commonly lumbar strain and ligament injury. Lifters who have disk degeneration and osteoarthritis are more prone to serious injuries such as disk herniation and lumbar radiculopathy. During powerlifting, certain exercises such as clean and jerk, dead lift, snatch, and squats are more stressful to the joints and muscles. The majority of episodes of acute low back pain in lifters are caused by lumbar sprain or strain [34, 35].

The athlete may present with a dull, pressure pain in the back, which is aggravated by stretching, coughing, and sneezing. It is associated with restriction of lumbar motion due to pain. The physical exam is usually benign and does not reveal any neurological deficit. Further diagnostic studies such as x-ray, MRI or CT scan are usually not required unless a more severe injury is suspected during the history and physical exam [34, 35].

The initial primary treatment is anti-inflammatory medications or low-dose oral corticosteroids. In some cases, muscle relaxants could be given. If there is swelling at the site of tenderness, cryotherapy is advised in the first 48 h followed by the application of heat [36, 37]. It is critical to be cautious while using heat or cold in spinal cord injury patients or any patient who has impaired sensation [38, 39]. Physical therapy is critical in lumbar sprain and strain to treat or prevent further damage and recurrence. In therapy three groups of muscles, which support the spine should be addressed: extensors, flexors, and rotators. The best therapy for low back pain should consist of low-impact aerobic exercise, core strengthening, hamstring stretching, and paraspinal muscles stretching/strengthening. In lumbar sprain, the lifter could start weight lifting in a couple of weeks but should start with lighter weight [4, 36, 37].

Prevention of Adaptive Weight Lifting Injuries

Besides proper warm up to stretch ligament, muscles, and tendon, using appropriate equipment could decrease the rate of the injuries significantly. Here are some tips on how to prevent wheelchair powerlifting injuries [40–42].

It is important to teach the athlete to control the bar, instead of having the bar control the athlete. This is possible by instructing the lifter to pull her-/himself under the bar rather than diving down to rock bottom on every attempt. It is imperative to avoid dropping a bar on weight lifter's head. The athlete should learn how to lock the arms, slightly flex the head, and shrug up hard [41, 42].

It is beneficial to use the arm cycle for warm up to improve the cardiac function and loosen up shoulder. It is recommended that the athlete wear gripping gloves to help improve hand movement and strength. It is also beneficial if these gloves are padded and extend above the wrist. Although the efficacy of them was questioned by some studies, it is generally used to reduce the chance of injury [40–42].

It is important to lift weights on an even surface which can decrease the rate of knee injuries since they are mostly caused by uneven platform [40–42].

Lastly it is always recommended to monitor the lifters blood pressure as the athletes with stage II hypertension (systolic pressure of 160 mm Hg or diastolic pressure of 100 mm Hg or higher) must be restricted from high static or isometric exercise, until their blood pressure is controlled [2, 3].

Conclusion

Wheelchair weight lifting became an official Paralympic sport in Tokyo Paralympic Games in 1964. It was not until 1984 that the other disability groups were granted permission to compete in these events. It took over 60 years for the remaining athletes such as lifters with any lower extremity impairments to be able to participate at Paralympic events. The sports are ruled by the IPC and are similar to those that apply in the powerlifting competitions for able-bodied athletes.

Poor technique and improper equipment usage may harm the lifters. The most common injury is the shoulder injury. Treatment depends on the severity of the damage. In order to prevent injuries, proper warm up and correct technique should be taught to all adaptive weight lifters.

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Adaptive Combative Sports (Judo, Boxing, Wrestling, Mixed Martial Arts)

27

Joseph L. Connor Jr., James G. Liadis, and Arthur Jason De Luigi

History of Combative Sports (Introduction)

Combat sports can be traced back through many ancient cultures as a form of testing the skills and strength of men, athletes, and warriors. One of the earlier forms of Olympic combat sport was called pankration in the seventh century B.C. This form of combative sport did not have any illegal maneuvers short of biting or gouging out the opponents' eyes [1]. Fortunately for athletes, the Olympic regulations have come a long way.

Over the centuries, fighting continued to remain popular through the dark ages, renaissance period, and into the modern era. In 1867, English prizefighting continued to advance and evolved into modern day boxing after the introduction of the Marquess of Queensberry rules, which first mentioned the use of gloves in tournaments [2]. The modern Olympic Games permitted amateur boxing in 1904. The United States popularized professional boxing in the 1920s through World War II and it continues to be a popular sport today.

Martial arts have been part of Asian cultures for centuries. Many disciplines exist across multiple cultures and regions. The martial art of judo was founded in Japan in 1882 as a form of jiujitsu [3]. The objective of judo is to throw or takedown an opponent to force them into submission or a pin. The Olympics adopted judo as an official sport in the Tokyo 1964 Olympic Games. The Paralympic sport of judo was later adopted in 1988.

Over the years, multiple forms of combat sports were merged together and became known as mixed martial arts (MMA). In MMA, the athletes are permitted to utilize any combination of techniques from multiple disciplines during competition. The chapter will focus on athletes with disability participating in the adaptive sports of judo, wrestling, MMA, and boxing as representatives for the vast variety of combative disciplines that exist worldwide.

Impairments in Combat Sports

The Paralympics currently only recognize the combat sport of judo, which is for visually impaired athletes. Constant contact with the opponent is necessary at all times, and the referee will interfere if contact is broken [4].

In the United States, athletes and organizations are promoting boxing, MMA, and wrestling to become more popular in the adaptive sports community. Some regional events are being held for athletes with upper and lower limb deficiencies due to congenital limb deformities, amputations,

J.L. Connor Jr., MD (✉) • J.G. Liadis, MD
A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA
e-mail: joseph.connor@medstar.net; James.liadis@medstar.net; ajweege@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_27

neuromuscular disorders (cerebral palsy for example), visual or hearing impairments, or intellectual impairments. In the United States, adaptive athletes are not commonly competing in any nationally recognized competitive organizations within a specified category or division. However, there have been some limb-deficient athletes and numerous hearing-impaired athletes at high school level wrestling who compete against able-bodied wrestlers [5–7]. One such athlete, Anthony Robles, competed in Division 1 wrestling at Arizona State University and won a NCAA national championship. Figures 27.1, 27.2, and 27.3 depict how an adaptive athlete with a spinal cord injury or stroke may participate in combat sport exercises or activities.

Fig. 27.1 An athlete with a spinal cord injury performs combat sport training

Fig. 27.2 Exercising using combat sport skills

Classifications/Rules

Combat sports tend to be one-on-one with each opponent having supportive team members in their corner. Athletes are matched by weight. There is a separation between amateur and professional competitions. The competitors are required to weigh-in to confirm their appropriate weight on the day of or day prior to the fight.

The unified rules and regulations of boxing and MMA are well defined by the Association of Boxing Commissions (ABC) and the Ultimate Fighting Championship (UFC), respectively. In these organizations, athletes are classified based on the competitors' weights, similar to the judo athletes in the Paralympics. Paralympic judo weight classes have been developed to establish competition against similarly sized athletes. Paralympic judo has established seven weight classes each in a Men's and Women's division and are listed in Table 27.1 [8].

Professional boxing rules in the United States are well defined by the ABC. The Association of

Fig. 27.3 An athlete with an excellent stroke recovery is warming up

Table 27.1 Paralympic judo men's and women's weight classes

Men's
<60 kg (extra-lightweight)
60–66 kg (half-lightweight)
66–73 kg (lightweight)
73–81 kg (half-middleweight)
81–90 kg (middleweight)
90–100 kg (half-heavyweight)
>100 kg (heavyweight)
Women's
<48 kg (extra-lightweight)
48–52 kg (half-lightweight)
52–57 kg (lightweight)
57–63 kg (half-middleweight)
63–70 kg (middleweight)
70–78 kg (half-heavyweight)
>78 kg (heavyweight)

Table 27.2 ABC unified rules of boxing [9]

1. Each round shall consist of a three (3) minute duration, with a one (1) minute rest period between rounds
2. The referee is the sole arbiter of a bout and is the only individual authorized to stop a contest
3. All bouts will be evaluated and scored by three (3) judges
4. The 10-point must system will be the standard system of scoring a bout
5. The mandatory eight (8) count after knockdowns will be the standard procedure in all bouts
6. All professional boxers are required to wear a mouthpiece during competition. The round cannot begin without the mouthpiece. If the mouthpiece is dislodged during competition, the referee will call time and have the mouthpiece replaced at the first opportune moment, without interfering with the immediate action. Points may be deducted by the referee if he feels the mouthpiece is being purposely spit out
7. There is no standing eight (8) count
8. There is no three (3) knockdown rule
9. A boxer shall receive a twenty (20) second count if the boxer is knocked out of the ring and onto the floor. The boxer is to be unassisted by spectators or his/her seconds. If assisted by anyone, the boxer may lose points or be disqualified with such a decision being within the sole discretion of the referee
10. A boxer who has been knocked down cannot be saved by the bell in any round.
11. If a boxer sustains an injury from a fair blow and the injury is severe enough to terminate the bout, the injured boxer shall lose by TKO
12. Injuries sustained by fouls (referenced in Table 27.3)

Ringside Physicians observes the following unified list of rules in Table 27.2 [9].

The UFC organization uses 5 minute rounds. Matches may reach three rounds, unless a championship match is taking place. Then, five total rounds would be the maximum. Note that the rules below are forbidden acts in the UFC (Table 27.4) [10].

Equipment

Combat sports are often hand to hand, but some sports, such as fencing, are considered combat sports as well as a pugilistic sport. Depending on

Table 27.3 Fouls

A. *Intentional fouls.*
1. If an intentional foul causes an injury and the injury is severe enough to terminate the bout immediately, the boxer causing the injury shall lose by disqualification
2. If an intentional foul causes an injury and the bout is allowed to continue, the referee shall notify the authorities and deduct two (2) points from the boxer who caused the foul. Point deductions for intentional fouls will be mandatory
3. If an intentional foul causes an injury and the injury results in the bout being stopped in a later round, the injured boxer will win by *technical decision* if he is ahead on the score cards; and the bout will result in a *technical draw* if the injured boxer is behind or even on the score cards
4. If the boxer injures himself while attempting to intentionally foul his opponent, the referee will not take any action in his favor, and this injury shall be the same as one produced by a fair blow
5. If the referee feels that a boxer has conducted himself in an unsportsmanlike manner, he may stop the bout and disqualify the boxer
B. *Accidental fouls*
1. If an accidental foul causes an injury severe enough for the referee to stop the bout immediately, the bout will result in a *no decision* if stopped before four (4) completed rounds. Four (4) rounds are complete when the bell rings signifying the end of the fourth round
2. If an accidental foul causes an injury severe enough for the referee to stop the bout after four (4) rounds have occurred, the bout will result in a *technical decision* awarded to the boxer who is ahead on the score cards at the time the bout is stopped
a. Partial or incomplete rounds will be scored. If no action has occurred, the round should be scored as an even round. This is at the discretion of the judges
13. A fighter who is hit with an accidental low blow must continue after a reasonable amount of time but no more than five (5) minutes, or he/she will lose the fight

the sport, the competitors may or may not wear specific protective equipment (Table 27.5) [11].

Apparel utilized in competition varies depending on the discipline utilized in the combative sport. Mostly, the athletes will wear some sort of shorts, briefs, singlet, gui, or judoka, with the addition of a protective bra for women. Boxing and wrestling permit shoes, where MMA does not permit footwear, due to allowing participants to utilize their foot as an offensive weapon [11].

Table 27.4 MMA unified rules [10]

Forbidden
1. Head butting or striking with the head in any manner
2. Eye gouging of any kind
3. Biting
4. Hair pulling
5. Fish hooking
6. Groin attacks of any kind
7. Placing a finger into any orifice or into any laceration of your opponent
8. Small joint manipulation
9. Deliberate strikes of the spine or back of the head
10. Throat strikes of any kind, including, without limitation, grabbing the trachea
11. Clawing, pinching, or twisting the flesh
12. Kicking the head of a grounded opponent (grounded: more than just the soles of the feet on the ground)
13. Stomping
14. Pile-driving your opponent into the mat
15. Purposely throwing your opponent out of the ring or caged area
16. Holding the shorts or gloves of an opponent
17. Engaging in any unsportsmanlike conduct
18. Holding the ropes or the fence
19. Attacking an opponent on or during the break
20. Attacking an opponent who is under the care of the referee
21. Attacking an opponent after the bell has sounded the end of the period of unarmed combat
22. Disregarding the instructions of the referee
23. Timidity, including, without limitation, avoiding contact with the opponent
24. Interference by the corner
25. Smothering (hand cupped over opponent's mouth)

Table 27.5 Protective equipment

1. Mouthpiece (often must be approved by ringside physician)
2. Gloves (fingered or fingerless depending on the discipline)
3. Groin protection for males
4. Chest protection for females
5. Head and ear protection (headgear should cover the eyebrows when properly fit)
6. Pads over elbows, knees, or shins

An athlete's supporting team members usually have a bucket, water bottle, towel, stool, and any other permitted items that are kept adjacent to the arena of competition and are brought into the ring or cage in between rounds [11].

Role of the Physician

The physician should be clearly identifiable and introduce themselves to inspectors/referees as well as any emergency medical staff. It is important for the physician to know the location of the local emergency department and trauma center. Prior to the event, the team physician and event coordinator should review an emergency action plan that would establish the best exit route from the ring or cage to the ambulance for transporting an athlete to the hospital efficiently. Furthermore, ringside physicians may require a stethoscope, sphygmomanometer, nasal speculum, ophthalmoscope, penlight, gauze, petroleum jelly, and gloves. Additionally, some venues or competitions will require an automated external defibrillator (AED) or cardiac life support kit, including a bag mask and oxygen, onsite. It may be required to have emergency medical services (EMS) on site and/or in the area with equipment for cervical spine stabilization. There should be equipment in preparation to provide airway management and possible ventilator support, should the fighter take a striking blow to the throat or neck.

Before the Match (Pre-competition Responsibilities)

Each opponent must have basic medical requirements for professional boxing or the UFC. Amateur divisions are less likely to require clearances, such as a baseline magnetic resonance imaging (MRI) or computerized tomography (CT) of the head, dilated eye exam, infectious disease screening, EKG, or blood count level. However, a general history and physical, including a neurologic exam, should be performed prior to participation. In limb-deficient athletes, ask about previous residual limb complications and perform a proper skin examination. Also, note neurologic impairments before the match to avoid any uncertainty if the deficit is new or premorbid. Pre-match exclusion criteria include, but are not limited to, acute or chronic infections, blood dyscrasias, hepatitis B, hepatitis C, HIV, retinal detachment, uncorrected visual acuity greater than 20/200 (greater than 20/60 for corrected vision), open lacerations, congenital cardiac abnormalities, pregnancy, unresolved post-concussive syndrome, organomegaly, or seizure in the past 3 years [11].

The physician should observe for any jewelry that the athlete is wearing. It should be removed to prevent it from tearing out or imbedding itself into tissue. Long hair should be tied back, but this is not required in all organizations. Glasses, dental braces, and breast implants are not permitted [11].

During the Match (Responsibilities During Competition)

The ringside physician has the right to stop any fight at any point in time to protect the fighters. This power must be used with caution, since the fighters are going to be inevitably injured to some degree. The physician should be confident and reasonable in his decision to stop a fight due to an injury which impairs the ability of the combatant to defend themselves. Things to consider would be altered mental status and laceration location, depth, and amount of bleeding. The physician should watch the competition, stay alert, and communicate with the referee. Referees often have to permit the physician to enter the ring for an emergent evaluation. It is imperative to watch and observe for changes in the athletes' momentum. Observe for signs of exhaustion and changes in strength or fighting style, as these may be signs of an unsafe fighter. Make use of counts when an athlete is down to observe for changes. Evaluate whether athletes are still able to defend themselves. Can they see in all visual fields? Can they rotate their neck laterally? Can they move their legs fast enough? Are they unable to use one or more limbs due to injury? All head injuries resulting in neurologic changes should lead to the removal of that athlete from competition. Sequential evaluation of the athlete should continue beyond the completion of the bout, assessing for symptoms in evolution.

After the Match (Post-competition Responsibilities)

Each athlete should be monitored after each match and evaluated if they have sustained significant injuries. In most professional events, athletes are taken for evaluation by ambulance. Keep in mind there are injuries that may take longer to present, such as a subdural hematoma [12]; therefore, serial evaluations are recommended.

Common Injuries and Management

Nasal Trauma

Epistaxis

Epistaxis is the most common symptom of nasal injuries. The presence of epistaxis indicates that the mucosa has been disrupted. It is critical to rule out an associated nasal bone or septal fracture [13]. Epistaxis can be divided into anterior or posterior divisions. Anterior epistaxis is more common with a history of trauma. Most of the time, anterior epistaxis occurs from Kiesselbach's plexus, also referred to as Little's area, in the anterior inferior nasal septum. Little's area accounts for nearly 90% of nose bleeds [14]. Posterior epistaxis is less common in general and even less commonly associated with trauma. The most prevalent site of posterior epistaxis is the Woodruff's plexus in the posterior middle turbinate. Posterior epistaxis can be more difficult to control and is dangerous, given the possibility of blood flow into the pharynx and the nature of arterial bleeds [15].

For anterior epistaxis, initial management includes local pressure using the thumb and finger pinch technique with the patient leaning forward for 5–20 minutes. If this approach is not successful, additional options include nasal packing, cautery, arterial ligation, or embolization. The athlete can be allowed to continue for moderate venous bleeding [16]. Indications to stop competition include blood running into the throat, pulsatile arterial bleeds, heavy venous bleeds, or epistaxis complicated by an acute fracture [17].

Nasal Septal Hematoma

Nasal septal hematomas are often associated with trauma and require prompt diagnosis and treatment. A hematoma is diagnosed via examination with a nasal speculum. It is critical to examine both nares, as septal hematomas can be bilateral if the blood dissects through a fracture of the nasal cartilage [13]. The septal cartilage has no blood supply of its own and receives oxygen and nutrients from the perichondrium. An untreated septal hematoma can cause saddle nose deformity via destruction of the septum [14]. Treatment involves immediate drainage using a large bore needle. If this is unsuccessful, it may require surgical drainage [18].

Nasal Fracture

The examiner should inspect for tenderness, crepitus, or abnormal movement. Rhinorrhea may represent a cerebrospinal fluid (CSF) leak. A nasal fracture may also be associated with a septal hematoma. Tenderness over the bridge can represent a fracture, since the nasal bones are thin [18]. An athlete can potentially continue to participate in the fight with a nasal fracture if the following criteria are met: (1) tenderness and swelling are isolated to the bony bridge of the nose, (2) the athlete can breathe through each naris, and (3) no septal deviation or hematoma is present.

However, if the signs/symptoms extend beyond these three conditions, the fight should be stopped, and the athlete should have facial radiographs.

Initial management of an uncomplicated nasal fracture includes ice and head elevation [19]. Uncomplicated displaced nasal fractures should be reduced within 6 h of injury. It is preferred that this reduction is immediate. It may be reasonable to have the patient follow up with otolaryngology in 3–5 days as cosmesis can be difficult to assess with swelling over the nasal bridge. If a nasal fracture is greater than 10 days old without previous intervention, the athlete should be referred to otolaryngology for further management [20].

Eyes

Subconjunctival Hemorrhage

Subconjunctival hemorrhage presents as blood in a well-circumscribed area overlying the sclera. This injury can be related to trauma, eye rubbing, performing Valsalva maneuver strenuously, or the use of anticoagulants. This is not a serious issue and can be treated with reassurance and cold compresses or moistening eye drops [21]; however, it is very noticeable and typically leads to increased concern of the athlete and their family.

Corneal Abrasion

A corneal abrasion can present as sudden onset of severe pain with perceived foreign body sensation. The patient may note blurry vision, photosensitivity, or tearing [22]. The diagnosis can be made via ophthalmoscope if on hand. However, slit lamp microscope paired with florescent dye has higher sensitivity. Treatment involves removal of any foreign bodies, topical antibiotics, and ophthalmologic follow-up [23]. Consider stopping the match if the athlete can no longer see or protect themselves adequately.

Periorbital Hematoma

A periorbital hematoma is known colloquially as a black eye and occurs secondary to the rupture of capillaries surrounding the orbit [24]. A ringside physician should only consider stopping a fight if the athlete has double vision, loss of sight, extraocular muscle palsy, fluid from the nose or ears, blood on the surface or inside the eyeball, ocular discharge, persistent headache, or signs of a medial orbital wall fracture, such as crepitus, enophthalmos, or entrapment [17]. Moderate periorbital swelling is often tolerable, but consider stopping the fight if the swelling is about to rupture or obstructs the vision of the athlete and subsequently endangers them for additional injury. Additionally, the ringside physician should evaluate the athlete's ability to see peripherally. If the swelling obstructs the vision of the athlete, this endangers the athlete as they may be unable to defend themselves due to visual field deficits [25], and thus the physician should discontinue the competition.

Hyphema

A hyphema is defined as blood in the anterior chamber of the eye. Compressive forces on the globe lead to damage to the vasculature supplying the iris, trabeculae, or ciliary body. Symptoms usually include blurry vision, headache, and photophobia. Diagnosis can usually be made without a slit lamp. Severity is graded based on the amount of the anterior chamber filled with blood [23]. The match must be stopped and a shield or patch must be placed on the eye prior to transfer to the ED or an ophthalmologist for immediate management. Treatment can include use of cycloplegics (atropine) and may require surgical intervention to decrease intraocular pressure if unable to be done medically [22].

Retinal Detachment

Retinal detachment is defined as the formation of a plane separating the retina from the underlying choroid. The area fills with vitreous fluid causing further separation. As the retinal cells are being deprived of oxygen from the underlying vasculature, it is critical to repair this quickly to prevent permanent damage [24]. This is an emergency situation and could result in permanent vision loss if not address immediately, and it is paramount that the ringside physician stop the match and send them to the ED. Symptoms of retinal detachment include flashing lights, floaters, blurred vision, or a shadow or curtain of light over an area of vision. All of which are typically painless [17]. Small retinal tears can be repaired using photocoagulation or cryopexy at the hospital to wall off the area of damage and prevent propagation. Large detachments generally require surgical correction with scleral buckling, vitrectomy, or pneumatic retinopexy [26].

Orbital Blowout Fracture

An orbital blowout fracture occurs as a result from trauma to the anterior eye leading to increased intraorbital pressure and resultant fracture at the weakest point of the orbital wall. Fractures of the orbital wall or floor allow the interorbital contents to displace into the paranasal sinuses with possible entrapment of the extraocular muscles (EOM) [23]. Most commonly, the orbital floor is fractured and can damage the infraorbital nerve or entrap the inferior rectus muscle. Signs of the injury include the affected eye turned up and out, diplopia, a palpable step-off deformity on palpation, ptosis, enophthalmos, periorbital edema, and ecchymosis [25]. A fight should be stopped since athlete requires a plain film radiograph followed by CT of the facial bones. In cases with minimal displacement and no EOM entrapment or nerve restriction, one may consider observation only. However, if there is enophthalmos greater than 2 mm, palpable emphysema, sensory disturbance of the infra- or supraorbital nerves, visual restriction, or diplopia, the patient will likely require surgery to repair the fracture and replace the orbital contents [22].

Facial Fractures

Nasal Fracture

Nasal fractures were discussed earlier in the chapter in the nasal trauma section.

Midface Fracture

Examination of the midface consists of examining for contusions over the zygoma, enophthalmos, malocclusion of the upper teeth, and anesthesia in the area of the infraorbital nerve or maxillary teeth. Grasping the anterior upper teeth and rocking the maxilla while stabilizing the forehead can assess instability. An unstable fracture should display increased mobility. The zygoma can be fractured due to its prominence, potentially with an adjacent fracture to the maxilla, orbit, or sphenoid bone [27]. Generally, these fractures should prompt cessation of the match and referral for surgical repair. Another clinical entity is the tripod fracture, which consists of fractures involving the zygoma, lateral orbit, and maxilla. Often caused by a forceful, direct blow to the orbit. More complex midface fractures are classified using the Lefort system [28]. Lefort I fractures are transverse fractures through the maxilla, above the roots of the teeth. Patients may present with malocclusion of the teeth. Physical examination of the Lefort type I fracture may show motion of the maxilla when the upper teeth are moved with the forehead held stationary by the examiner. Lefort II fractures extend superiorly to include the maxilla and midface, often forming a pyramid shape when they are bilateral. During physical examination of a Lefort type II fracture, the examiner may note nasal motion with the maxilla when the upper teeth are grasped and rocked with the forehead held stationary. Lefort type III fractures are complex fractures. These cause craniofacial dissociation, often involving nasal bridge fractures extending into the medial and lateral orbital walls and zygomatic arch. Lefort type III fractures involve CSF leak and require neurosurgical consultation [29].

Mandible Fractures

The mandible is the strongest facial bone, but it is at risk for fracture in combative sports. Mandibular fractures can present with an obvious deformity, inability to open the jaw, difficulty chewing or talking, or tooth malocclusion. Diagnosis can be made with radiographs and CT when needed and the fight should be stopped. Surgical repair often involves jaw fixation or plate placement with antibiotic prophylaxis [12].

Lacerations

Facial lacerations are common in combative sports. They occur as a result of compression of the skin and subcutaneous tissues against the underlying facial bones. The priority is determining if these are dangerous to the athlete and require the match to be stopped [30]. Specific lacerations prompting the fight to be stopped include any laceration that interferes with the fighter's ability to see and protect themselves. Other serious lacerations are those that include the tarsal plate and the lacrimal gland, both of which require operative repair. Any laceration directly over an underlying nerve will require cessation of the fight. Additionally, lip lacerations progressing to the lip border are at risk for significant extension and the fight should be stopped [17]. Facial lacerations should be repaired from inside to outside in layers. The internal layers should be repaired with dissolvable sutures. After laceration repair, the fighter should not damage the area for 45 days to allow for the tissue to reach at least 75% of its tensile strength [31]. Not all ringside physicians are comfortable performing the repair and may send the athlete to the ED.

Concussion

Concussions are frequent injuries in combat sports and often mild or with out loss of consciousness. Monitor athletes for altered mental status, loss of consciousness, voluntary movement of extremities, and signs of a seizure [32].

With loss of consciousness, take the first immediate necessary actions of assessing the ABCs:

A—airway protection by cervical spine stabilization and removal of the mouthpiece
B—breathing
C—circulation (compressions for cardiac arrest)
D—neurological examination with pupillary responses and Glasgow Coma Scale

Pupillary responses should be monitored for intracranial pressure elevation, but this test is not sensitive in the first minute of unconsciousness [32]. Loss of consciousness for more than 1–2 min should initiate emergent transfer to the emergency department by stretcher. They should remain in the supine position until a return towards baseline can be observed. Regression of mental status is an alert to transfer the patient. Do not hesitate to apply minor restraint against the athlete who is confused and tries to get up. Once further improvement is observed, they may sit, then stand, then walk to their corner where a neurological evaluation should be performed. If the athlete continues to show a return towards baseline and there are no focal neurologic deficits, they may be supervised by the coach, family, or responsible person to monitor for any further changes. On the other hand, 24 h observation in a hospital is not excessive. Hospital evaluation is warranted if the athlete has nausea, vomiting, amnesia, headache, dizziness, speech impairment, or gait impairment [32].

Summary

The combat sports, while part of competitive athletics for centuries, have become more popular in the past several years. This popularity also extends to those athletes with disabilities, enabling individuals to experience the physical and emotional benefits that these activities can confer, improving quality of life [33]. This section covered the basic rules, regulations, and classifications, which apply to judo, boxing, wrestling, and mixed martial arts. After reading this chapter, the reader should feel comfortable with the physician's role in a match, as well as in managing a variety of possible injuries. This includes the role of the physician prior to, during, and after each match.

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Adaptive Extreme Sports

28

William Denq and B. Elizabeth Delasobera

Introduction

High risk, adrenaline, action—these are the hallmarks of an extreme sport. Once thought to be inaccessible, the arena of extreme sports is now quickly becoming a cultural norm for adaptive athletes. Increasing media exposure and advancements in technology have allowed the recreational participant to be involved in extreme sports in a fun yet protected manner.

The goal of this chapter is to provide an educational resource about adaptive extreme sports to physicians and therapists who may be treating these individuals as well as educating their patients about these adventurous sporting activities. The chapter will have introductions to each sport and discuss the specialized equipment used, common injuries, and prevention techniques—so that medical providers may educate and manage the recreational and competitive adaptive athlete (Image 28.1).

W. Denq, MD (✉)
George Washington University, Washington, DC, USA
e-mail: william.denq@gmail.com

B. Elizabeth Delasobera, MD, CAQSM
MedStar Washington Hospital Center, Georgetown University, Washington, DC, USA
e-mail: bronson.e.delasobera@medstar.net

Adaptive Rock Climbing

As a sport, rock climbing is increasingly popular in both the recreational and competitive world. As of 2015, up to 9 million Americans climb a year [1]. The sport offers a physically demanding outlet that is easily accessible for many different groups, including adaptive climbers. Many rock climbing gyms are now equipped with adaptive climbing equipment. It is the combination of the access to these gyms and the desire for the athlete with a disability to challenge him-/herself which is leading to its increase in popularity.

Classifications

The International Federation of Sport Climbing (IFSC) Paraclimbing has strict categories in order to ensure equal opportunity during competitions. As a standardization method, a medical panel assesses each competitor to determine the category they fit in. They have a customized examination method to calculate the ability coefficient of those with a neurophysical disability. Additionally, any artificial aids that are used must be presented to the medical panel for evaluation.

Styles of Climbing

There are various styles of climbing that can be utilized by the adaptive athlete as well as

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_28

Image 28.1 Jarem Frye with a specialized prosthetic knee at El Capitan in Yosemite Park. Courtesy of Craig DeMartino

the able-bodied climber. Climbing utilizes a belayer the person on the ground who secures the climber. It is the belayer's duty to keep an eye on the climber's progress and let out slack to the line by releasing the belay. The belay is a special device that locks the rope a little at a time as the climber slowly ascends. The two major categories that climbing is broken down into is free climbing and aid climbing. Free climbing relies on the natural holds of the course with equipment used to prevent falls. It includes, but is not limited to, bouldering, top roping, and lead climbing. In contrast, aid climbing relies on the use of devices that affix to the course that act as artificial holds. This allows the climber to ascend more safely.

Bouldering can be done indoors or outdoors. It is a low height course where the climber ascends without a safety rope or aid. Safety is dependent on the height and a crash pad that is placed underneath the climber to cushion any falls that may occur.

Top roping can be done indoors or outdoors. The belayer is on the ground with the rope anchored at the top of the course. The rope runs through the harness of the lead climber to ensure maximum safety for both belayer and climber. Typically the climber will use pre-existing grip holds to ascend the wall without the use of aids.

Lead climbing can be done indoors or outdoors. This is a style where the lead climber is attached to a rope that runs through anchors. The rope is connected to the belayer. Progress is achieved by the lead climber ascending beyond the anchor point to attach rope to the next point. In contrast to top roping, the rope is not anchored to the top of the course. As a result, this is a riskier style of climbing that results in larger injuries.

Aid climbing is performed outdoors. The climber ascends by utilizing specialized equipment not typically seen in free climbing. The equipment can be used to create artificial holds in the natural rock surface of a course. Some of these holds or anchors are permanently placed by the climber to mark the course for a future climber. These holds are called fixed protection. Other equipment used by the aid climber attaches to the fixed protection to allow for ascent. A typically safer method of climbing, aid climbing is used for the tougher courses where free climbing (bouldering, top roping, lead climbing) is dangerous or not easily achieved.

Rules of Competition

The rules of the World Paraclimbing Championships are set forth by the International Federation of Sport Climbing (IFSC). The organization defines three types of paraclimbing competition. They are lead, boulder, and speed. Competitors are placed in a specific disability category as referenced in Table 28.1. If there are not enough competitors to be placed in a category, the entrant may opt to compete in the next higher category.

In the lead competition, an artificial wall with purposeful design is used. The wall is a required

Table 28.1 Disability classifications in the IFSC World Paraclimbing Championship [2]

Disability	Neurological/physical disability (NPD)	Visual impairment	Amputee	Wheelchair/seated
Category	NPD1: Assessed ability coefficient ≤1.4	B1: Blind	AA1: One arm amputee	WS1: Competitors normally requiring a wheelchair
Category	NPD2: Assessed ability coefficient >1.4	B2: Visual acuity up to 2/60 and/or visual field <5%	LA1: One/two leg amputee (with/without prosthesis)	
Category		B3: Visual acuity between 2–6/60 and/or visual field 5–20%		

minimum height of 12 meters (m), length of 15 m, and width of 3 m. There are two rounds, a qualifying and final round. Competitors that are in category B1–3 are allowed to receive instruction from a coach with regulation communication equipment.

In the boulder competition, an artificial wall with purposeful design is used. However, this wall must not put the lowest part of the climber's body greater than 3 m above the landing mat. There are two rounds, a qualifying and final round.

In the speed competition, an artificial wall with purposeful design is used. This wall is 10–15 m in length. A minimum of two parallel lanes allow for a side-by-side race. The type of climbing in these speed competitions is top-rope.

Adaptive Equipment

Climbers endure significant strain to their body and risk serious falls. As a result, the equipment used needs to be rugged and reliable. There is equipment that is utilized by all climbers regardless if they are able bodied or have a disability. Not all adaptive climbers require special equipment and augment their prostheses or residual limb with standard equipment. We will review the standard climbing equipment as well as some adaptations for athletes with a variety of disabilities.

Standard Equipment

The most basic of climbing equipment used in all types of climbing is the climbing shoe. It typically has a thin vulcanized rubber layer to provide a higher coefficient of friction and, therefore, better foot grip. To improve handgrip, climbers will apply a fine layer of chalk to reduce sweat and increase friction. An overapplication of chalk will reduce friction and therefore, grip.

A harness is the core for safety in top roping, lead climbing, and aid climbing. It typically is designed to wrap around the waist and is what fastens the climber to a safety rope. The rope is hooked to an anchor, runs through a loop in the harness, and attaches to a belayer at the bottom. The belayer uses a belay device to help lock a climber in place if they start to fall. It is also used to help the climber descend at a safe and paced rate.

The courses in aid climbing have very few climbing holds. As a result, a variety of equipment is used in aid climbing and is what differentiates it from free climbing. Protection devices are equipment used to provide temporary anchor points. Ascenders are used to ascend a rope without necessarily using climbing holds. Aiders are short ladders that can be fixed to an anchor point to allow for difficult courses to be more navigable. This short explanation is by no means exhaustive as there are many types of aid climbing equipment.

Neurological/Physical Disability/ Seated

Adaptive climbers in the neurological/physical disability (NPD) and seated category have a variety of specialized equipment available to provide safety in the climb. A chest harness can be used in place or in conjunction with a standard waist harness. This is used to secure the climber and to help keep them upright. There are other types of custom harnesses that modify the standard waist harness to better hold and distribute weight for the adaptive climber.

Image 28.2 A climber utilizing the pullup bar to ascend a course. Courtesy of Paradox Sports

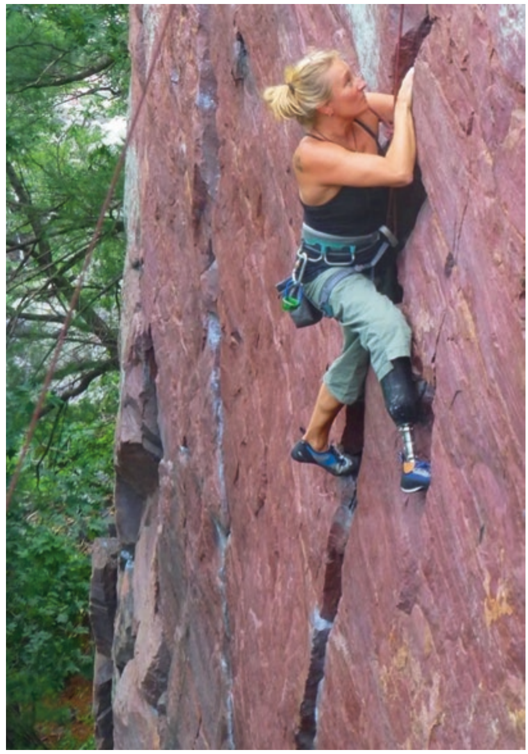

Image 28.3 Chris Prange-Morgan with a prosthetic limb climbing Birch Tree Crack at Devil's Lake. Courtesy of Able Outdoors

Pullup bars (Image 28.2) are utilized by climbers with disabilities such as lower limb paralysis to ascend a wall. The bar is fixed to a pulley system that allows the climber to ascend the route through a locking mechanism. Several famous adaptive climbers have used this equipment to climb tough routes such as El Capitan in Yosemite, one of the world's largest exposed granite monoliths. Many rock climbing gyms are now adaptive climber friendly and have custom pulley systems that can accommodate different harnesses, wheelchairs, and pullup bars.

Limb-Deficient Athlete

Most limb-deficient climbers do not require specialized equipment to climb. They may choose to use their regular prosthesis to help achieve balance and traction. However, several companies are now developing specialized climbing prosthesis and equipment to allow for more rigorous and difficult climbing.

Athletes with upper limb deficiencies due to amputation or congenital deficiency may use terminal devices, such as a hand or hook, that are built to withstand environment factors and the stresses that come with climbing. The prosthetic socket can use a vacuum suspension to prevent the prosthesis itself from detaching while under strain. An alternative cable system is available to allow for better grip by modifying the standard open and closing motions.

The athlete with lower limb deficiency may also use terminal devices which can be a climbing foot or knee. The climbing foot (Image 28.3) comes in different varieties, but the general design intent is to shorten and contour the foot from a standard prosthetic foot. This decreases the torque and allows the foot to better utilize small crevices. A climbing shoe or climbing sole is placed around the foot for traction. The climbing knee (Image 28.1) is designed with lightweight metal and shock resistors—a coil and air. It is built to withstand not only the large amount of pressure exerted when climbing but the environment it may be used in.

Injuries

Injuries are overwhelmingly common in both the recreational and elite rock climbers. It has been reported that 75% of these athletes will suffer from either a traumatic or overuse injury [3]. Up to 93% of injuries are an overuse injury while the remainder are due to a traumatic injury [4]. The types of injuries tend to be sprains, strains, chronic overuse, lacerations, dislocations, and fractures. As the sport grows, initial research demonstrates several risk factors associated with injuries:

1. Outdoor climbing versus indoor climbing [1, 5]
2. Increasing climbing experience [6]
3. Increasing climbing intensity score (CIS) [6]
4. Lead climbing [6] and bouldering [7]
5. Increasing BMI [4]

The risks with climbing compared to paraclimbing are similar. However, there are additional risks of adaptive climbing related to the type of disability, equipment used, and the additional compensatory force required to overcome certain physical disabilities.

For the adaptive athlete, ambulatory athletes (visually impaired, amputee, cerebral palsy) are at increased risk for lower limb injuries [8]. Lower limb-deficient athletes have a predilection for injury to regions proximal to their residual limb. This is due to increasing the necessary rotation, flexion, and extension of those groups to achieve increased excursion and propulsion [9]. Additionally, the residual limb at the point of contact with prosthesis is at risk for increased skin injury. The contralateral intact limb will endure similarly increased forces as the groups proximal to the residual limb. It is at risk for chronic overuse injuries [10]. There is always a risk for skin injuries at the point of contact with the prosthesis. Upper limb-deficient athletes are at similar risks as athletes with lower limb deficiency as with regard to residual and intact limb. Wheelchair athletes are at increased risk for upper limb injuries [8].

Adaptive climbers are still at risk for injuries experienced by the standard climber. Upper extremity injuries tend to compose anywhere from 57 to 82% of all injuries while lower extremities and trunk comprise the rest [7, 11]. Table 28.2 demonstrates the most common injuries associated by body part.

Table 28.2 Most common injuries associated with body part [7]

Body part	Most common injuries
Fingers	Sprains, strains, chronic overuse injury, lacerations
Elbow	Chronic overuse injury
Foot	Lacerations, fractures
Ankle	Lacerations, fractures, sprains, strains

Upper extremity injuries, acute and chronic, occur in about 75% of all rock climbers [3]. About 60% of these injuries are at the hand or wrist [3, 7, 11]. The other 40% involves the shoulder or elbow.

Of the hand or wrist injuries, finger tendon injuries comprise of 52–57% of injuries [1, 11]. This is due to the reliance and incredible strain on the fingers. The different types of grips, hooked, open-crimp, closed-crimp, open-hand, and pocket grip can predispose the climber to these tendon injuries. The most common tendon injuries are the flexor digitorum superficialis (FDS) and profundus tendons (FDP) and sheaths [12] and annular tendon injuries [1, 11]. In general, climbers will exert 380 Newtons (N) of force on an annular tendon—a 70 kg climber could exert as much as 450 N of force when falling [13]. The maximum tension that the strongest annular pulley, the A2 pulley, can withstand is 400 N [1]. The proximal interphalangeal (PIP) joint collateral ligaments are also commonly injured—they are seen in up to 50% of elite climbers [3].

The other hand or wrist injuries typically consist of strains, lacerations, abrasions, fractures, and dislocations. These injuries can result in chronic disease that may impair the rock climber such as volar subluxation of the PIP joint, collateral ligament sprains and tears, contractures, and early osteoarthritis [1].

The shoulder is the second most common injured site and encompasses roughly 9–17% of all injuries [7, 11, 14]. Superior labral tears, impingement, anterior dislocations with labral tears, biceps tendon overuse injuries, tears or ruptures, and supraspinatus tendinopathies are the most self-reported injuries [11].

The elbow consists of around 8% of injuries in climbers [11]. Climber's elbow is one of the more culturally recognizable pathologies. Starting as a pain in the cubital fossa, it is a layman's term for brachialis myotendinous junction strains. The brachialis muscle is utilized frequently as the typical motion for a climber to ascend is pronation and flexion. Golfer's elbow, or medical epicondylitis, is also regularly seen.

Lower extremity injuries comprise anywhere from 6 to 27.6% of all injuries [7, 11]. However, when analyzing acute and traumatic injuries, almost 50% are lower extremity injuries [15]. The typical mechanism is due to a fall from height. The most common knee injuries are the anterior cruciate, posterior cruciate, collateral ligament tears, and patellar dislocations [1]. The most common foot injuries are contusions, calcaneus fractures, talus fractures, ankle fractures, and ankle sprain with lateral ligament injury [15]. Modern climbing shoes force the foot into a concave shape with a majority of pressure on the big toe. As a result, there are many chronic injuries that can result such as hallux valgus deformity, subungual hematomas, nail bed infections, and neurological complaints [15]. Acute injury to the superior peroneal retinaculum, while rare, can result due to the extreme pressure experienced by the big toe and foot [1].

Injury Prevention

Although the literature is still developing for rock climbing, modifying some of the risk factors listed in the above section may reduce the risk of injury. Low-weight, high-intensity training and general physical fitness and conditioning can reduce muscle fatigue and be protective against both acute and chronic injuries. Finger strengthening exercises are protective against the typical tendon injuries seen and are easily accomplished anywhere. There are a variety of equipment available as well as common household items that can be used to strengthen the fingers. Certain handheld devices that incorporate resistance against each finger are useful for improving flexor strength. A soft stress ball can replace this for grip strengthening exercises. Rubber bands placed across two fingers to provide resistance while extending a finger can be used to aid in improving extensor strength. There are multiple taping methods across the sport, but the only one to demonstrate significant difference is the H-tape method. This is a taping method shown to strengthen a finger with a pulley injury [16]. However, it is not shown to be prophylactic for pulley injuries. There is no other taping method that has been shown to prevent injuries.

Adaptive SCUBA Diving

SCUBA (self-contained underwater breathing apparatus) diving has consistently been a popular sport for the past several decades. Its advantage over snorkeling is the ability to explore at greater depths in the water. The possibility for SCUBA diving initially started in 1942 with Jacques-Yves Cousteau and Emilie Gagnan who invented the first modern diving demand valve. Since its commercialization, millions in the United States have become certified divers. As a recreational sport, it has become increasingly popular for the adaptive population. The sense of weightlessness and freedom provided by diving is especially enjoyed by those with mobility constraints on land (Image 28.4). It has many therapeutic aspects and is an excellent form of physical activity. This section will cover the necessary qualifications to SCUBA dive, injuries, and special considerations for adaptive divers.

Certification, Rules, and Regulations

Traditionally, SCUBA diving has been a recreational sport. Certified divers can participate in underwater exploration and photography, archaeology, fishing, and tour guiding. The military and professional fields have other uses for SCUBA diving such as ship inspection, search and rescue, scientific experiments, and ocean mapping.

Recently, as early as 2007, international competitions for sports diving have emerged. Largely popular in Europe, these events challenge individuals and teams to push the limits of recreational SCUBA diving techniques in a swimming pool. There are timed races, obstacle courses, and

Image 28.4 A bilateral amputee enjoying the weightlessness and freedom experienced with diving. Courtesy of SUDS Diving, Inc., and John W. Thompson

Table 28.3 Certification levels provided by the HSA [17]

Certification level	Required safety and permissions
A	Can function as a buddy Can dive with another certified SCUBA diver
B	Requires two dive buddies at least certified Level A
C	Requires two dive buddies: • Certified rescue diver • Certified Level A or above

search and retrieve events. As these competitions develop and interest by the disabled community continue to grow, para-athlete involvement becomes increasingly possible.

As seen in Table 28.3, the Handicapped SCUBA Association (HSA) developed guidelines for the certification of an adaptive diver. They have strict physical performance requirements in order to ensure the safety of the diver. The physical performance of the diver will determine the level of certification they receive. Levels range from A to C and dictate the amount of assistance that the diver requires. For example, a Level A diver only requires anothe r certified SCUBA diver. The Level A diver can also function as a dive buddy for a Level B or C diver. The reason why a Level B diver requires two dive buddies is because one is for the Level B diver and the other is a standard dive buddy for the Level A diver. Essentially, the third diver functions as a safety diver for the buddy assisting the Level B or C diver.

Equipment and Technique

The phases of SCUBA diving are surface floating, descent, bottom, and ascent. Descent during SCUBA diving tends to be horizontal while ascent tends to be vertical. Appropriate balance during the dive is achieved through fine motor motions of the extremities and trunk.

Special equipment is necessary to achieve all phases of SCUBA diving. The most basic for all divers is a mask, snorkel, and fins. The mask serves to provide a large visual field and an enclosure for the nose to allow for pressure changes. A snorkel can be attached to the mask to allow for surface breathing and preservation of available oxygen in the tank. Fins serve to help propel the diver through the water at a faster pace with less energy.

The following equipment is what allows divers to attain greater depths and explore for a longer time than snorkeling or free diving. A buoyancy control device (BCD) is typically worn around the chest. Through bladders, weight pockets, valves, inflator, and a deflator, the BCD gives the diver control over their depth. It also is the device that holds the tank. In addition to the weight pockets of the BCD, weight belts can also be used as an adjunct for descent. Wet suits and dry suits are used to protect the diver from the environment. This protection is limited not only to temperature but the surrounding rocks, ledges, and debris in the water as well.

The demand valve developed by Cousteau and Gagnan, in basic design, is still used today as a part of the diving regulator. The regulator is the most important piece of equipment that allows divers to survive without surface oxygen. Pressurized air from the tank is reduced to ambient pressure by the regulator and demand valve to allow for comfortable breathing on demand. The regulator is typically attached to the tank, BCD, and submersible pressure gauge (SPG). The SPG helps to detect how much air is left in the tank.

Adaptive Equipment

Limb-Deficient Divers

Due to the deficiency of a single or multiple limbs, the adaptive diver will have an increased buoyancy. This is also the case with divers with atrophied extremities. Therefore, a weight-integrated BCD without a weight belt is less confining and allows for better mobility in the water. Typically, upper-limb amputees will be able to operate standard equipment.

With regard to the lower limb-deficient athlete, ankle weights may also be used to help counter the additional buoyancy inherent to the diver. The diver with a unilateral lower extremity limb deficiency who chooses to dive without a custom prosthesis will wear one fin—as a result, balance and control of body movement in the water require greater finesse. A stiff fin over a split fin may provide better torque for changing position in the water [18]. Divers with limb deficiencies of bilateral limbs may have customized prosthetics to allow for fitting of fins as seen in Image 28.5. The prosthetic itself cannot be a day-to-day use prosthetic as it needs to be noncorrosive and able to drain. Additionally, webbed fingers or a motorized propulsion device (Image 28.6) will help to improve propulsion.

Neurodisability

Divers with a neurodisability have atrophied extremities that will interfere with appropriate buoyancy, balance, and propulsion. They also may not be able to fully access their equipment. A variety of support is available to aid these divers.

Wet suits can be modified with zippers and hook-and-loop strips to decrease the diver's difficulty in donning and offing the suits. Hard-soled dive boots are available to provide maximum protection for the diver's feet and additional flotation for the diver's legs [19]. An octopus regulator has two separate demand valves that allow for a diver and his/her buddy to share a tank. Motorized propulsion devices (Image 28.6) or

Image 28.5 Lower-limb amputee with custom prosthetic. Courtesy of SUDS Diving, Inc. and John W. Thompson

Image 28.6 Motorized propulsion device. Courtesy of SUDS Diving, Inc. and John W. Thompson

webbed fingers aid in improved propulsion. A dedicated dive assistant can help with the whole dive as basic skills such as flooding, clearing, and removal of the SCUBA mask [19].

Specialized diving equipment is not required for the diver who is visually impaired (VI). However, significant planning including underwater current patterns and signals. The sighted diver can lead, with the blind diver following the sound of air bubbles, or the blind diver can lead, with the sighted diver tracking location for the course of direction to return to the boat. Without proprioceptive inputs in an environment without gravity, the VI diver may become disoriented about up and down. Orientation is achieved by placing a hand over the bubbles as they leave the regulator, to feel in which direction they are rising. If the bubbles are going toward the feet, the diver can readjust position [20].

Injuries

The most common injuries related to SCUBA diving are barotrauma, decompression sickness, and drowning-related injuries [21]. There are additional considerations to the adaptive diver that are reviewed below.

Decompression sickness is a disease of ascent. Ascent even within the diving table puts a diver at risk for increased nitrogen release from tissues. This release causes bubbles to form which then can obstruct arteries, veins, or lymphatics [22]. Symptoms may develop within the first 8 h but may take up to 24 h after the dive to present. A variety of mild manifestations may occur such as pruritus, rash, fatigue, headache, and nausea. The most common complaint is joint pain [23]. More serious manifestations occur in the neurological system. Hemorrhagic infarcts, axonal degeneration, and severe demyelination may occur [22] resulting in a variety of neurological deficits. Occlusion of the venous plexus around the spinal cord can result in venous stasis, ischemia, and temporary/permanent disability. Although the adaptive diver has not been shown to be at increased risk, a higher attention to detail needs to be paid to divers with preexisting neurological disabilities.

Pulmonary decompression sickness may occur within minutes of surfacing from the dive [22]. Symptoms present with chest pain, shortness of breath, or cough. The pathophysiology is similar to adult respiratory distress syndrome and necessitates urgent care at the emergency room [24].

A similar concern to decompression sickness is the arterial gas embolism (AGE). Rapid ascent without exhalation (and even sometimes with exhalation) may result in air trapping.

This air trapping results in barotrauma that can cause air emboli to collect in organs such as the brain. Neurological deficits from this may be difficult to discern in the already neurologically impaired diver. There is a two times risk in the diver population with asthma for arterial gas embolism. The concern with asthma is additional air trapping that can cause pulmonary barotrauma. Asthma can increase the risk from about 1 in 200,000 to 1 in 100,000 [24].

Pulmonary barotrauma is also a disease of ascent. If a diver does not adequately exhale, the compressed air that is now experiencing less pressure will begin to expand in the lungs. This can cause rupture of pulmonary alveoli and escape of air into the mediastinum. Divers may complain of chest pain or shortness of breath. Pneumothorax and pneumomediastinum are possibly life-threatening injuries that require urgent care and intervention. Inhalation of 100% oxygen at the surface may help to alleviate symptoms and disease, but some pneumothoraces may require immediate needle decompression and chest tube. If there is suspicion for decompression sickness or arterial gas embolism that requires hyperbaric chambers, a patient with a pneumothorax may require a chest tube to prevent a tension pneumothorax from forming.

Barotitis media or "middle ear squeeze" is one of the most common barotraumas [22]. This is a result of eustachian tube dysfunction typically caused by an inflammatory process such as an upper respiratory tract infection or allergies. Divers will typically complain of ear pain, vertigo, or hearing loss. The tympanic membrane may also rupture due to the "squeeze." Antibiotics should be considered in this case. Pseudoephedrine taken 30 min before a dive has been shown to decrease the incidence and severity of barotitis media in novice divers [22]. However, there is a concern with the medicine. Given the synergistic effects on a diver's alertness with a medication such as diphenhydramine used in allergies or other antihistamines used to treat seasickness, pseudoephedrine should be used cautiously.

Inner ear barotrauma occurs through different mechanisms that result in transmission of pressure to the inner ear. One of these mechanisms is suggested as forceful attempts to clear the middle ear by opening the eustachian tubes. The eustachian tubes may become locked if a pressure differential of greater than 90 mmHg is achieved and typically occurs when diving to greater than 100 m of depth in the seawater [25]. This repeated maneuver results in an increase in the ambient pressure experienced by the inner ear. This may cause rupture of the inner membrane and/or a labyrinthine window fistula [25].

Inner ear barotrauma is a very difficult diagnosis to differentiate from inner ear decompression sickness because the symptoms are both sensorineural hearing loss, tinnitus, and vertigo. Hyperbaric chamber treatment for inner ear decompression may worsen inner ear damage. Although different history and physical examination findings have been suggested, none have been demonstrated to be sensitive or specific. If there is concern for either inner ear barotrauma or inner ear decompression sickness, an urgent visit to the emergency room is advised.

Other types of barotrauma can occur during descent. Any noncompressible, gas-filled cavity is at risk for the pressure differential exerted by the environment that the SCUBA diver experiences [26]. The following barotraumas are diseases of descent. Barodontalgia or "tooth squeeze" results in tooth or maxillary sinus pain. Athletes should avoid diving within 24 h of a dental procedure. Aerogastralgia or gastrointestinal barotrauma results in abdominal cramping and belching. This is a self-limited disease. Mask squeeze results in corneal injection or subconjunctival hemorrhage which can be avoided by ventilating the mask while diving [22].

Divers with sensory deficits are at increased risk for sustaining and not realizing skin trauma such as sunburns, abrasions, lacerations, bites, stings, or pressure sores. These injuries will be more common in the diver that has a body less conditioned to handle equipment such as buoyancy control devices. Typically a full body wet suit and sunscreen will help to protect the diver. However, intermittent assessments for skin integrity are crucial to prevent future complications.

Adaptive divers, such as those with cerebral palsy, muscle dystrophies, and spinal cord injuries tend to be more prone for osteoporosis and fractures. This can be due to medications such as chronic steroids and the lack of physical activity [27]. The treating physician should be vigilant to any edema, erythema, or deformity that may indicate a fracture that the patient may be insensate to. Injury prevention can include access platforms that are close to water level. This facilitates for easier transfer and decreased risk of injury.

Special Considerations for the Adaptive Diver

The incredible pressures experienced by divers at the depths of the ocean places an undue stress on the regular devices that adaptive athletes have implanted. VP shunts, cochlear implants, and intrathecal baclofen pumps are the medical implants that will be covered below.

Ventriculoperitoneal (VP) shunts are placed to help relieve fluid accumulation in the brain. The performance of these shunts at different atmospheres (atm) similar to the SCUBA environment has been studied. The results have matched the theory that all spaces will respond similarly to an increased atmospheric pressure. Preliminary results did not demonstrate any shunt malfunctions up to 4 atm [18]. However, given that this is a new field, there may be unforeseen complications associated with SCUBA diving that have not been discovered.

Cochlear implants are placed in the inner ear to bypass the nonfunctional anatomy. These implants provide direct stimulation of the auditory nerve. Small studies have been done to evaluate the performance of implants at different atm pressures as well. Results have demonstrated a tolerance to damage or failure of up to 6 atm [28].

Intrathecal pumps are medical devices that are used to deliver medications to the spinal cord. A case report has been written about retrograde CSF leak into the pump due to being exposed to hyperbaric oxygen therapy. There is a similar concern with the increased atmospheres an adaptive SCUBA diver will encounter. Manufacturers do not recommend exposure to greater than 2 atm with these pumps [28].

Divers will not only experience an incredible stress on their devices but their bodies as well. Divers with spina bifida or spinal cord injuries tend to have smaller diameter vessels and increased shear stress [29]. This makes them susceptible when diving at lower depths. The compressed air of suits that thermoprotects divers will decrease in volume as the atmospheres increase. This puts the adaptive diver at increased risk for hypothermia and autonomic dysreflexia (for T6 and above) [28]. Diving in warmer water can help to prevent this.

The diver with risk for congestive heart failure or history of congestive heart failure may experience onset of symptoms when entering the water. Blood is shifted into central circulation and may cause extravasation of fluid into the lungs due to water immersion [24]. An immersion in cold water may also increase the myocardial demand [30]. Additionally, divers who rely on their upper limbs to balance in and propel through the water experience an increased myocardial oxygen demand [31]. Therefore, athletes with history of cardiac disease require further evaluation if they complain of chest pain, shortness of breath, or lightheadedness.

Adaptive athletes, such as those with cerebral palsy, will have a predilection for seizures [32]. Seizure disorder requiring ongoing medical management is a strict contraindication to SCUBA diving [28]. A diver candidate with a seizure history is not accepted for training unless that diver has been free from seizures for at least 5 years and no longer requires medication [24].

Water immersion and the cold environment that divers experience can induce increased renal excretion. This is known as immersion diuresis. Many proposed mechanisms have been proposed for this phenomenon [33–36]. The two concerns are bladder distension and dehydration. Divers that require intermittent urinary catheterizations should identify dive boats that have private spaces available for bladder management and a means of washing hands to maintain the aseptic nature of the procedures [28].

Athletes afflicted by spina bifida can be at increased risk for latex allergy. Twenty-two to fifty-six percentage of spina bifida patients are estimated to have a latex allergy [37–39]. Although the majority of equipment used is latex free, there may be seals and tubing that may contain latex [28]. A detailed examination of the materials used in all of the equipment would be prudent.

End of Chapter Summary

Once thought to be a daunting and formidable arena, the world of extreme sports is quickly becoming more accessible to the adaptive athlete. Competitions in rock climbing will become fiercer, and SCUBA diving may begin to see an addition of a competitive element in a traditionally recreational sport. As a result, associated injuries and demand for healthcare professionals familiar with these injuries will rise accordingly. There are life-threatening injuries that should be treated expeditiously. However, this should not be a firm barrier to adaptive athletes interested in participating in these sports. They can experience the freedom, exhilaration, competition, and exploration provided by these sports as long as there is a healthcare professional willing to guide safe practice.

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Part IV

Selected Topics in Adaptive Sports Medicine

29 Adaptive Sports Event Planning

Jeffrey C. Leggit and Chelsea D. Brundage

Abbreviations

AED	Automated external defibrillator
BLS	Basic life support
I/O	Intraosseous
IM	Intramuscular
IOC	International Olympic Committee
IV	Intravenous
NSAID	Nonsteroidal anti-inflammatory drug
O2	Oxygen
PTT	Push-to-talk
VPA	Volunteer Protection Act

Benjamin Franklin is credited with saying "If you fail to plan, you are planning to fail!" This axiom holds true in terms of medical support for an adaptive sporting event. Accepting responsibility as medical director for a mass participation athletic competition can be incredibly fulfilling and challenging at the same time. Prior to accepting this responsibility, the first question to be asked is if there is an adequate amount of time for proper planning, both in terms of actual calendar days and your schedule. Second, what is the relationship between the sponsoring organization, yourself, and the medical team?

This chapter will discuss the various planning factors that must be considered to provide outstanding medical support. The ultimate goal is to allow all participants to compete to their maximal ability in a safe and healthy environment. In general the medical planning for an adaptive event is the same for an able-bodied event with a few additional factors that will be discussed in the following pages [1]. Suggestions, examples, and checklists will be presented to serve as a template for a variety of different situations.

Preplanning

Event planning should occur at least 6 months prior to the proposed activity date. Rarely this can be adjusted for very small events, but on the corollary larger events require more time. The relationship between the sponsoring organization, the medical director, and the medical team needs to be firmly established. As you are preparing to accept the role as a medical director, there are very important and pertinent questions you should be asking. Is it strictly voluntary or is there compensation? The variance on this arrangement has implications on liability coverage. What is under the medical director's authority? What

J.C. Leggit, MD, CAQSM (✉)
Department of Family Medicine, Uniformed Services University of the Health Sciences, Bethesda, MD, USA
e-mail: jeff.leggit@usuhs.edu

C.D. Brundage, MD
Department of Physical Medicine and Rehabilitation, Fort Belvoir Community Hospital, Fort Belvoir, VA, USA
e-mail: guererra@yahoo.com

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_29

are the venue, date of event, start times, event postponement/cancelation guidelines, and rules regarding who can compete? Is there a budget and appropriate staff for medical support? What level of medical and lay volunteers can be counted on? Who will solicit and manage those volunteers?

Another fundamental question is what level of care should be provided? If it is a single day event, the minimum standard is basic life support (BLS) and emergency medical care. Multiday event coverage is more complex. A decision must be made whether rehabilitative and illness care will be offered and to what extent. This will have a direct effect on the level of resources, both with personnel and equipment, which must be secured prior to and during the event. It should be noted that there are several local and national entities around the country that can be contracted to provide these services if funds are available. Another option is to combine some level of volunteer and contracted support.

Although general principals prevail no matter how many participants are competing, no matter how many events are occurring, and no matter how long the competition last, the answers to these questions dictate what planning must take place. The following provides a list of some of the common questions that must be answered:

- Location
- Time of year
- Events
- Indoor vs. outdoor vs. combination
- Multiday
- Level of athlete (to include international competitors)

Once a venue has been selected, it is incumbent on the medical director to perform a site visit. At the venue the following elements should be addressed:

- Terrain
- Evacuation routes
- Communications
- Dead spots for communication
- Coordination with local resources (medical, police, fire, city authorities)
- Unique factors to the area (environment, infections, food, culture, safety)
- Is there a fixed facility that you can operate out of or is tentage required?
- Power/water source
- Restrooms and handwashing facilities

When selecting the medical area, it should be ideally close to the finish line. Although fixed facilities are enticing for numerous reasons, they are not always practical. When using a tent/portable shelter, several factors must be considered. Who will set up and tear down? Is there an ability to control the climate? Is the area prone to flooding? The medical site must have adequate ingress and egress routes that will not be blocked by athletes or spectators.

Multiday events prevent many unique challenges. In terms of medical supplies, will all expected supplies be brought at once, or will a restocking of supplies be required? Who will clean the facility in between events and days? What is the feeding, housing, and transportation plan for the medical team and for the athletes?

A risk assessment for endogenous infectious diseases, crime, and terrorism should occur. Local authorities can assist if you are unfamiliar with the area. The Center for Disease Control and Prevention as well as the American Red Cross has updated information on their websites that can be invaluable. Multiday events present the greatest risk as athletes, spectators, and event staff might be unfamiliar with the area and may put themselves unknowingly at risk. Furthermore events such as the 2013 Boston Marathon remind us that terrorism is a constant concern. Rival teams can also create fanaticism which must be considered.

Will an on-site ambulance be required/necessary? If the risk assessment calls for such, who will provide this service and at what cost? Which hospitals will the ambulances transfer to and has pre-event coordination been accomplished? Coordinating with the local medical support was listed as one of the task upon the site visit. The importance of this cannot be overstated. You must know what level of support they are capable of and willing to provide with accurate contact information.

Medical staff must be easily identified, and this requires prior planning to ensure an adequate amount of identification is available. We recommend identification badges with medical roles to be worn at all times. Additionally, medical staff may wear hats or bibs which easily and quickly identify them as being part of the health-care team. Hats and bibs avoid the need for different sizes of shirts.

A task list with a person of contact annotated for each task is highly recommended. Synchronization meetings (virtually or in-person) should be conducted at a minimum monthly until 30 days prior to the event (T-30). At T-30, weekly follow-ups are recommended until T-7 days and then daily follow-ups until the actual event. A suggested time line follows:

- 3–6 months—Secure support staff and perform site visit.
- 1–3 months—Complete communications, emergency action, and logistical plan.
- 1–4 weeks—Publish all plans, conduct rehearsals, and order all logistics.
- 7 days—All logistics on hand.

Rehearsals

Communication synchronization should take place prior to the event, and there should be a contingency plan with some sort of redundancy. Mobile phones are most often used and allow the ability for phone, texting, web posting, or emailing. Although technically speaking a mobile/cellular phone is a two-way radio, a dedicated push-to-talk (PTT) two-way radio communication is recommended either as primary communication or as a backup to cellular phones. PTT has the advantage of instant communication and the ability to broadcast the same message to a large group. The type and amount needed are dictated by the event, terrain, and number of expected users. It is incumbent to pretest the communication plan (as well as publishing it) throughout the entire event area to discover "dead" zones and have appropriate mitigation steps in place.

Written medical protocols/flow charts and emergency action plans (EAP) should be disseminated, posted, and rehearsed. The following lists some scenarios that should have an emergency action plan:

- Cardiac arrest
- Asthma
- Anaphylaxis
- Exertional heat stroke/injury
- Exercise-associated collapse
- Dehydration
- Hyponatremia
- Hypothermia
- Life-/limb-threatening trauma

This list should be modified for the events being covered. For instance, water, elevated altitude (>8000 feet), and winter events present unique challenges that require special equipment and training. The protocols should be distributed well ahead of the event and should be rehearsed. A suggested schedule is to disseminate protocols 30 days prior with virtual rehearsals at the ensuing synchronization meetings. In-person rehearsals must happen prior to actual event. Their timing depends on the size of the event, but 48 hours prior will allow for adjustment should the protocols or roles need to be clarified.

A mass causality situation must always be considered. At a minimum a predetermined location for all medical personnel to report immediately upon notification should be established. This will allow for dissemination of the new medical plan in response to the situation [2].

Unless an event is scheduled indoors, weather is the variable that cannot be controlled and is often poorly predicted. Consideration to postponing an event should occur if the wet bulb globe temperature is greater than 28 °C (82 °F) or less than 20 °C (4 °F) [3, 4]. Lightning injuries also must be anticipated. Lightning injuries affect 800 to 1000 persons per year with 40 fatalities, 62% of those occurring in organized sporting events [5]. This has spurred the following saying: "If you see it, flee it. If you can hear it, clear it." [6] Meaning if you see lightning or hear thunder you must seek appropriate shelter. Appropriate shelter is defined as a fully enclosed building that has some sort of electrical grounding (i.e., plumbing or wiring) [6]. If a fixed structure is unavailable, a vehicle with a hard metal roof (team bus) can serve as a substitute. The sound of thunder implies that lightning is likely within 8–10 miles and capable of striking the area. In general 30 min must pass without visible lightning or audible thunder prior to resuming activities. The only caveat to this is at night where lightning can be seen at greater distance than during the day. At night if no thunder is present but lightning is visible, it may be safe to proceed with competition [7].

Injury Surveillance and Medical Clearance

Surveillance of injuries is an essential component of the planned medical care. It provides the historical record on which to base future decisions and a record keeping of events that happen in the medical tent. Likewise medical clearance prior to competition is essential to protect the long-term health of athletes.

To perform surveillance of injuries, one must establish a definition of injury that applies to all sports included in the event. There are multiple injury surveillance studies that have been performed during tournaments involving single sport events. There are fewer studies surveying injuries sustained during multisport events. The most robust data come from the International Olympic Committee (IOC) approach to injury surveillance. The IOC surveillance takes into account a consensus definition of injury, injury report by the physician responsible for the athlete, report related to a time period independent of whether or not an injury occurred, and one report form per team (not per injury) [8]. This model of injury surveillance has been successfully implemented during the Paralympic Winter Games in Salt Lake in 2002 and the Paralympic Summer Games in 2008 in Beijing and serves as an excellent tool for multisport event coverage.

International consensus defines injury as a musculoskeletal complaint newly incurred due to competition and/or training that receives medical attention [8]. This definition is inclusive of any complaint that requires medical attention, not just those resulting in reduced performance or time away from competition. Yet it fails to take into account preexisting conditions and those which have not been fully rehabilitated prior to competition. Both of these factors can predispose the athlete to reinjury during competition as well as having an impact on the use of medical resources during event coverage. We suggest that injury should be defined so as to include both preexisting conditions as well as new complaints sustained during the period of competition and would better predict the medical requirement needed to support the event. The inclusion of both types of injury can be documented and tracked and can help direct future care at sporting events.

For multiday events, injuries should be reported daily for an individual athlete or team. Features of the injury report include athlete identification number, sport and event, round/heat/training, date and time of injury, injured body part, type of injury, cause of injury, and an estimate of the expected duration of subsequent absence from competition or training. An example of such an injury report form is demonstrated in Fig. 29.1. Likewise any illnesses incurred while athletes are present and participating in sporting events should be tracked on an illness report form, which is demonstrated in Fig. 29.2. In simplest terms, any medical encounter that an athlete, staff, or spectator has with the medical team should be accounted for to ensure accurate epidemiology. In general 70% of all encounters will be for injuries and 30% for illnesses [9]. The most commonly affected organ systems are the respiratory (34.2%) followed by gastrointestinal (9%). Tracking should include follow-up of any patient that was evacuated or referred to higher level of care. The tracking system must be rehearsed and understood by those who will be entering the information for it to be of any use during the competition and afterward.

Prior to competition all athletes should receive medical clearance from their primary care, sports, or team physician. Consideration should be made for requiring and collecting the medical clearance forms and ensuring that they have the adaptive

Pt ID	Date/Time	Athlete	Days Absent From Activity	Training or Competition	Sport/Event	Injured Body Part	Type of Injury	Cause	New or Chronic
						1 Face (incl. eye, ear, nose)	1 Concussion (regardless of LOC)	1 Overuse (gradual onset)	
						2 Head	2 Fracture (traumatic)	2 Overuse (sudden onset)	
						3 Neck / cervical spine	3 Stress fracture (overuse)	3 Non-contact trauma	
						4 Thoracic spine / upper back	4 Other bone injuries	4 Recurrence of previous injury	
						5 Sternum / ribs	5 Dislocation, subluxation	11 Contact with another athlete	
						6 Lumbar spine / lower back	6 Tendon rupture	12 Contact: moving object (e.g. puck)	
						7 Abdomen	7 Ligamentous rupture	13 Contact: stagnant object (e.g. pole)	
						8 Pelvis / sacrum / buttock	8 Sprain (injury of joint and / or ligaments)	14 Violation of rules (obstruction, pushing)	
						11 Shoulder / clavicle	9 Lesion of meniscus or cartilage	21 Field of play conditions	
						12 Upper arm	10 Strain / muscle rupture / tear	22 Weather condition	
						13 Elbow	11 Contusion / haematoma / bruise	23 Equipment failure	
						14 Forearm	12 Tendinosis / tendinopathy	24 Other	
						15 Wrist	13 Arthritis / synovitis / bursitis		
						16 Hand	14 Fasciitis / aponeurosis injury		
						17 Finger	15 Impingement		
						18 Thumb	16 Laceration / abrasion / skin lesion		
						21 Hip	17 Dental injury / broken tooth		
						22 Groin	18 Nerve injury / spinal cord injury		
						23 Thigh (a: anterior / p: posterior)	19 Muscle cramps or spasm		
						24 Knee (m: medial / l: lateral)	20 Other		
						25 Lower leg (a: anterior / p: posterior)			
						26 Achilles tendon			
						27 Ankle (m: medial / l: lateral)			
						28 Foot / toe			

Fig. 29.1 Daily report on injury form. The consensus options in each category are included. Adapted with permission [8]

Pt ID	Date and Time	Athlete	Days Absent from Activity	Diagnosis	Sport/Event	Affected System	Main Symptom	Cause
		Yes				1 Respiratory / Ear, nose, throat	1 Fever	1 Pre-existing (e.g. asthma, allergy)
		No				2 Gastrointestinal	2 Pain	2 Infection
						3 Urogenital / Gynecological	3 Diarrhea, vomiting	3 Exercise-induced
						4 Cardiovascular	4 Dyspnea, cough	4 Environmental
						5 Allergic / Immunological	5 Palpitations	5 Reaction to medication
						6 Metabolic / Endocrinological	6 Hyperthermia	6 Other
						7 Hematologic	7 Hypothermia	
						8 Neurologic / Psychiatric	8 Dehydration	
						9 Dermatologic	9 Syncope, collapse	
						10 Musculoskeletal	10 Anaphylaxis	
						11 Dental	11 Lethargy, dizziness	
						12 Other	12 Other	

Fig. 29.2 Daily report on illnesses form. The consensus options in each category are included. Adapted with permission [8]

athlete's pertinent medical history. This will help if an athlete is unresponsive. In addition it will greatly aid if classification is required to place athletes in appropriate ability groups. Protection of the athlete's health information is paramount, and processes should be in place to ensure no violations occur. Competitors should be required to sign a waiver acknowledging the physical requirements needed for the event(s) that they are competing of their own free will, that there is a risk of injury, and that the event organizers are not responsible for any injury or illness which may result. The waivers can also state the level of medical support that will be available and serve as an informed consent. We recommend waivers be reviewed by the organizer's legal counsel prior to introduction to the athletes. Although these waivers do not guarantee avoidance of a malpractice claim, they do provide a layer of protection. The waivers should also be accompanied by an education packet of the physical demands needed to successfully complete the activities in addition to suggested training strategies to accomplish the requirements. As mentioned earlier a discussion should occur at the planning stage if some applicants will be disqualified from competing. In general though for the spirit of the games in adaptive sports, the event organizers should attempt to make every accommodation possible for an athlete to compete as long it is safe for all competitors and does not violate the rules of the competition.

Liability/Medical Malpractice

The medical director must know who is providing the malpractice insurance coverage and the provisions of the coverage for the medical staff. Did the event organizers purchase liability insurance that would specifically cover health-care providers, or does it just cover the liability for the event planning organization? It is incorrect to assume the Good Samaritan laws will provide adequate liability alone and in some cases may be deemed non-applicable to the health-care providers. In general Good Samaritan laws are designed to protect health-care providers who, while not in any official medical capacity, render aid within their scope of practice (i.e., while driving they witness a car accident and stop to render assistance). Good Samaritan laws are state specific, nuanced, and do not protect against gross negligence or misconduct and provide no financial support for legal defense. These laws do not apply while volunteering to support an event and definitely do not apply if you are compensated in any way. Therefore, if the health-care provider is specifically providing official medical coverage (whether compensated or not), they need to seek alternate liability coverage options.

On the other hand, the Federal Volunteer Protection Act (VPA) does provide a degree of coverage according to the Association of State And Territorial Health Officials; the Federal VPA "provides protection to nonprofit organizations' and governmental entities' volunteers for harm caused by their acts or omissions on behalf of the organization or entity. The act does not require that an emergency declaration be in place for its protections to apply." [10] As in the Good Samaritan law, any compensation negates the act, and the Federal VPA does not protect the volunteer from legal action taking from the event organizers. The Federal VPA applies to:

- Uncompensated volunteers
- Volunteers properly licensed, certified, or authorized by state law
- Volunteers of nonprofit organizations or governmental entities
- Acts within a volunteer's scope of responsibility
- Acts of ordinary negligence

It does not apply to:

- Willful or criminal misconduct, gross negligence, reckless misconduct, or a conscious, flagrant indifference to the rights or safety of the individual(s) harmed by the volunteer
- Harm caused by operating a motor vehicle, vessel, aircraft, or other vehicle for which the state requires its operator to possess an operator's license or maintain insurance
- Volunteers for businesses
- The organization or entity utilizing the volunteer

There are also State VPAs which may or may not afford greater protection. All volunteer medical providers are encouraged to check with their malpractice insurer for further information.

Whether you are even allowed to provide care as a team/event physician if the competition is in a venue other than where you are licensed depends on the state. Table 29.1 lists the state licensing boards that would and would not allow out-of-state licensed team physicians to care for athletes in their state [11]. There is an ongoing effort by sports medicine organizations such as the American Medical Society of

Table 29.1 State medical licensing board response to "Can the traveling physician practice in your state?" [11]

No	Yes
AK, AL, AZ, DC, GA, FL, HI, ID, IL, KS, LA, MA, MD, ME, MI, MO NE, NJ, NM, ND, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, VT, WI, WV	AR, CA, CO, CT, DE, IA, IN, KY, MN, MS, MT, NH, NC, UT, VA, WA, WY

Sports Medicine (AMSSM) to enact a policy/statute which provides legal provisions allowing sports medicine medical staff traveling with their teams to another state to provide medical services to their team. Rules change and state licensing boards should be contacted for the latest information for proper planning. Military physicians must be cognizant that they are only legally protected while performing their function in an official capacity to eligible beneficiaries. They also must adhere to the privileging requirements of the local military treatment facility in the area where they may be practicing. They are not covered by the military when providing volunteer services to a civilian cohort unless they are doing so as part of their military duty.

Event Coverage

The medical support logistical footprint is greatly influenced by the venue and events being covered. The two constructs for medical support are distributed care and consolidated care. In general a combination of the two is ideal if feasible with space, equipment, and personnel. The majority of resources should be concentrated somewhere near the finish line or in a central location if multiple activities are occurring in different venues. Road races should generally have some sort of first aid or checkpoint at least every 3 km [12]. There is debate about what level of care should be at these stations. The final decision will be dictated by the type of event, distance/time it would take to get to the main medical tent or definitive care, and the number of trained personnel. If travel time is greater than 10 min to the main medical tent or emergency facility, then at a minimum Basic Life Support (BLS) supplies with an automated external defibrillator (AED) and epinephrine for anaphylaxis should be available. A reliable communication method as discussed above is paramount. Another option is a roving aid station that follows competitors. Each venue and event is unique, but as stated earlier, prior planning will ensure services are available when required.

Personnel

Medical coverage organizers must estimate personnel and medical equipment which will be required to support the entire duration of the competition. This is best accomplished by reviewing data from previous iterations of the same event. Should these reports not be available or if the activity has changed substantially, then reviewing historical norms of similar events can guide the estimate. General guidelines suggest that approximately 10% of competitors may require medical care [12]. This estimate can differ though depending on the types of activity. Cycling and triathlons averaged 5%, while multisport and obstacle course events averaged 30% [13, 14]. It is suggested that for every 1000 participants there should be 20 providers with 5–8 being physicians. Nursing and medic personnel should make up at least 50%–75% of the staffing [13]. With very large multiday events, support from radiology and pharmacy may be considered. Depending on the care being offered (i.e., multiday events where ongoing care is offered), a physical therapist or athletic trainer can be considered as well. A suggested distribution is 80% of assets around the finish line or main medical tent, with 10% roving and 10% distributed along aid stations [12]. These estimates do not include administrative personnel. For every 20 health-care providers, 5–10 lay administrative personnel should be available. They can help with crowd control, record keeping, and some patient transport [13].

Many athletes and teams will travel with their own medical support. The medical director should confer with the athlete/team medical support to ensure an understanding of what role they will play. In multiday events at a minimum, there should be a medic or nurse manning the tent 24 hours a day to triage with a physician on call should immediate care be warranted. As mentioned previously, high-risk events will require prior coordination with local medical authorities in the case of a mass casualty that overwhelms the capabilities of event planning assets.

Medical Supplies

To properly prepare for medical coverage of a multisport event, organizers must predict as precisely as possible the medical equipment which will be required for support. What to bring and how much depends on the actual event, with multiday events requiring more logistical support. Proximity to local health-care resources and the level of care that is predetermined are other additional factors that should be integrated into the planning process. A good conceptual planning tool is an organ system approach such as in Table 29.2. The list is not all inclusive nor is each item mandatory. Instead, within each category both equipment and medications should be considered as well as approximate amounts based on the expected injuries/illnesses, casualty estimates, and resupply plan mentioned previously. One must not forget about infection control to include personal protection, patients, and equipment.

If stocking roving patrols or aid stations, a much smaller "medical bag" concept can be utilized. In an online survey of team physicians from the AMSSM and the American Orthopedic Society for Sports Medicine (AOSSM) covering community, high school, collegiate, and professional sporting events, Everline documented usage frequency of supplies stocked in medical bags and described a consensus recommendation for sideline preparation [15]. The most highly desired and frequently used items identified during this survey included alcohol swabs, bandage scissors, adhesive bandages,

Table 29.2 Medical equipment and medication

Category	Equipment to consider	Medications to consider
Emergency/BLS	AED(defibrillator/pacer), ice sheets/baths	Nitroglycerin, aspirin, atropine, and adenosine
Trauma	IV material, I/O needle, and tourniquet	IV fluids
Wound management	Various bandages/gauze, suture material, liquid adhesive, irrigation equipment, cotton tip applicators, hemostats, and forceps	Local anesthetic, antibiotics (topical, oral, injectable)
Pain		NSAID (oral & IM), acetaminophen
Allergic		epinephrine, antihistamine, and steroids
Airway/pulmonary	Bag valve mask, O2, and spacer	Beta-agonist, antibiotics
Oral/dental	Tongue depressors, dental kit, and lip balm	Antibiotics
Ocular	Ophthalmoscope, eye kit	Antibiotics. Saline
Ear	Otoscope	Antibiotics
Nose	Nasal packing, silver nitrate stick, and nasal speculum	Topical medication (vasoconstrictor/decongestant, lubricant)
Gastrointestinal		Antiemetic, antidiarrheal, and antibiotic
Skin	Blister care	Antibiotics(topical, oral) steroid (topical, oral), and sunscreen
Genitourinary	Urine dipstick, catheters, and speculum	Antibiotics, antifungal
Endocrine	Ability to check blood sugar	Dextrose, insulin
Musculoskeletal	Ice packs, braces, splints, and elastic wraps	Injectables
Neurologic	Reflex hammer	Benzodiazepine, migraine medication
Infection control	Gloves (multiple sizes), masks, goggles, disinfectant (for procedures and equipment), sterile prep material (alcohol pads, chlorhexidine, Betadine), and hand sanitizer	
Diagnostic	Blood pressure, thermometer (to include rectal), point of care electrolyte device, stethoscope, and ultrasound	
Administrative	Charting, pens, folders, papers, and inventory management system	
Miscellaneous	Needles, syringes, sharps containers, scissors, light source, biohazard bags, tampons/sanitary napkins, blankets, change of clothes, suction device, tools for prosthetic adjustments, stretchers/litters, litter stands, wheelchairs, crutches, and bags for medication dispensing	

This is not an all-inclusive or a required supply list but is intended to help medical directors consider all systems when planning what equipment and medications they intend to have at the event. Quantity will be determined by expected patient volume and ability to resupply disinfectants, non-sterile gloves, and a stethoscope. Other items such as sterile gloves, local anesthetic, eye kits, a suture set, butterfly closures, wound irrigation materials, a blood pressure cuff, short acting β-agonist inhalers, syringes, eye kit, flashlight, and a reflex hammer were often included in medical bags but seldom used. The American College of Sports Medicine (ACSM), working in collaboration with the American Academy of Family Physicians (AAFP), the American Academy of Orthopedic Surgeons (AAOS), AMSSM, AOSSM, and the American Osteopathic Academy of Sports Medicine (AOASM) introduced a consensus statement in 2012 proposing similar contents to be included in medical bags which can be viewed at http://journals.lww.com/acsm-msse/pages/articleviewer.aspx?year=2012&issue=12000&article=00024&type=Fulltext [16].

If providing field side coverage, equipment needed at a minimum includes gloves and wound management supplies. In addition to bandages, skin adhesives, and tape, the ability to clean off blood on equipment to allow competition to continue is recommended. A suggested mixture is 30 mL bleach, 15 mL detergent, and 250 mL water in a spray bottle mixed fresh each day [13]. It is also suggested that an anaphylaxis kit (epinephrine and beta-agonist) accompanies field side bags along with noting the closest AED. There must be access to an AED at the main medical tent, the roving medical team if employed, and aid stations if transport time is greater than 10 min. There must also be access to local emergency medical services able to transport athletes or spectators to a higher level of care.

Unique to adaptive sporting events, the medical provider must plan for the individual needs of their athletes. Examples include athletes with limb deficiency who may require prosthetic adjustments and skin care, or spinal cord-injured patients who may require help managing bowel and bladder or noxious stimuli to avoid developing autonomic dysreflexia. In support of such events, medical providers should plan to be in contact with a prosthetist, have skin care supplies, and stock items such as catheters. Pre-education is recommended for the entire medical staff on how to care for the unique medical needs of the adaptive athlete. If physical therapists or athletic trainers are utilized they must have the requisite equipment to support their scope of practice. An additional consideration that should be taken into account when planning for equipment requirements for a multiday even is resupply. The longer the event, the higher the patient load, and the more frequently resupply should take place.

Event planners must take into account the potential need to care for heat and cold/exposure injuries thus including rapid cooling and hydration supplies as well as rapid rewarming equipment, respectively. Strong consideration should be given to the inclusion of ice baths/sheets if heat injuries are expected and strategic placement depending on events and venues. Management of heat injuries must be rehearsed and documented in an EAP. Similarly a point of care electrolyte measuring device is recommended to help manage possible hyponatremia and hypo/hyperglycemic conditions. Additionally, medical providers should expect that nonathletes may report for care during multisport events, thus requiring a protocol to be in place to either provide care to the nonathlete or refer to a local medical facility.

The actual physical layout of the medical area depends on the resources available, but some general principals are constant. There should be a single portal of entry that is wide enough or expandable to allow stretchers to pass through. There should also be a single portal of exit. These can be the same portal if so desired. There should be an immediate triage area with some level of privacy, and this should be manned by a knowledgeable staff member with the ability to discern the truly urgent/emergent from routine patient. The size of the triage area will depend on the events being covered. For a single large event like a marathon, the triage area should be fairly large; for multiday multisport events with lower number of participants in each event, the triage area can be mostly ambulatory and not as large. There should be a separate area for medical/illness-related conditions and for musculoskeletal conditions. When planning the utilization of space, it is important to consider having a holding area that is to the side of the treatment area for those patients that you would like to observe for a period of time. There should also be consideration of having an area for exams that require exposing the patient and a quiet area for patients with traumatic brain injury, posttraumatic stress disorder, or similar conditions that would benefit from fewer stimuli. There needs to be plans for the potential development of hypothermia either from the environment itself or after competing and assuming a recumbent posture to rest. Therefore, blankets as well as warm fluids to rehydrate and warm the athlete.

Only patients and their medical attendants should be allowed in the medical area. This is where lay volunteers can be invaluable. The medical team should also be cognizant and wary of rival competitors being treated at the same time. There are multiple anecdotal stories of mayhem ensuing from the battle on the athletic field carrying over into the medical area. Separate rivals whenever possible and do not allow their teammates or fans in the area.

There should be significant pre-event planning regarding hydration and nutrition during endurance, multi-heat and multiday events. The medical director should be prepared to provide advice to race organizers on what are effective strategies as well as disseminating information to participants prior to the event to aid with their training. In general thirst should dictate replenishment of fluids during events to avoid dilutional hyponatremia from overhydration. One suggestion is 6–12 oz. (180–360 mL) of chilled fluid for every 15–20 min of continuous activity with additional fluid choices containing carbohydrate and sodium for events involving continuous activity lasting more than 1 h. There is significant debate in the medical literature and with expert opinion on the best fluid options, and the medical director should make the final decision of what resources will be available. Once a final plan is determined, the fluid choices and locations should be published prior to the event and with adequate signage during the event [17].

After-Action Review

Event planners should consider integrating a daily feedback mechanism to facilitate the gathering of information at the end of a day to address issues that arose. Following the completion of the adaptive event, feedback must be gathered from participants, volunteers, and providers. Questions to be discussed should include what went well and what could be improved upon? Was there a lack of supply or resupply? Was there proper communication? Did any issues arise that had not been considered prior to the event? Were mechanisms in place to address these issues with event organizers? If one were planning this event the following season/year, what would be changed? All of these questions should be asked within a short time of the completion of coverage so that events are fresh in participants', volunteers', and providers' minds. With such continuous after-action review, each subsequent day and event builds upon the success of the preceding day/event.

Conclusion

Successful medical coverage for adaptive sporting event requires preplanning well in advance of the event. Each event and venue is unique and will determine the amount of support in terms of equipment and personnel. Coordination with local resources and dress rehearsals are essential for a successful event. Multiday events are more logistically challenging and incur the added components of resupply, housing, and feeding of athletes and staff. An injury surveillance system should be used for proper tracking and to provide historic norms for future planning. Providers must verify how malpractice coverage will occur and who has what decision-making authority for the event. The ultimate goal for medical support is to ensure an equitable, safe, and fulfilling experience for the athlete.

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Policy and Advocacy Initiatives to Promote the Benefits of Sports Participation for Individuals with Disability

30

Angelie Mascarinas and Cheri Blauwet

Abbreviations

ABA	Architectural Barriers Act
ADA	Americans with Disabilities Act
CDC	Centers for Disease Control and Prevention
CIFT	Certified Inclusive Fitness Trainers
DOJ	Department of Justice Civil Rights Division
DOT	Department of Transportation
ECAC	Eastern College Athletic Conference
IDEA	Individuals with Disabilities Education Act
NCAA	National Collegiate Athletic Association
NCHPAD	National Center on Health, Physical Activity and Disability
SCI	Spinal Cord Injury

Introduction

Individuals with disabilities frequently experience multiple health disadvantages compared to the general population such as excessive weight/obesity, hypertension, tobacco usage, limited engagement in physical activities, and higher unemployment rates. These factors typically lead to lower income, receiving less social and emotional support, and having difficulty in obtaining essential healthcare [1]. In many regards, engagement in physical activity, either through individual fitness programs or organized sports, provides an opportunity to optimize health and decrease the risk of acquiring chronic disease. This chapter will discuss the current health disparities that impact people with disabilities, outline the barriers and facilitators to physical activity participation, summarize the public health programs established to address these disparities, and review relevant public policy and legislation that have been instituted to promote universal access to sport and fitness opportunities.

A. Mascarinas, MD (✉) • C. Blauwet, MD
Spaulding Rehabilitation Hospital Department of PM&R, Harvard Medical School, 300 First Avenue, Charlestown, MA 02129, USA
e-mail: amascarinas@partners.organd; amascarinas@gmail.com; cblauwet@partners.org

Disability and Health Disparities

Many personal, social, and environmental factors influence the ability of individuals with disabilities to access healthcare and engage in physical activity. According to the World Health Organization International Classification of Functioning, Disability and Health (ICF), disability goes far beyond one's diagnosis and rather is a complex interplay between functional impairment, activity limitations, restriction in participation, environmental factors, and personal factors [2]. All of these may influence,

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_30

and at times hinder, access to physical activity and wellness programs, thus impacting health. Although a comprehensive review is outside the scope of this chapter, several examples will be reviewed here.

Higher Rates of Obesity and Chronic Disease Among Individuals with Disability

People with disabilities are more likely to experience the effects of chronic, noncommunicable disease when compared to the general population. A cross-disability study showed that obese adults with disabilities were more likely than obese individuals without a disability to have elevated blood pressure, high total cholesterol, and diabetes [3]. People with disabilities are also more likely to smoke and be overweight/obese when compared with the general population, putting this community at higher risk for heart disease and many forms of cancer [4]. Specifically, data from the 2001–2005 National Health Interview Survey noted a higher prevalence of obesity in the disability population (28.4%) compared to those without disability (17.8%) for ages 18–44 years—a trend that continues with aging [4]. Similarly, the Longitudinal Health and Intellectual Disabilities Study found that adults with intellectual disability have a higher prevalence of obesity (38.3 vs. 28%) and morbid obesity (7.4 vs. 4.2%) when compared to the general population [5]. Finally, adults with lower extremity mobility difficulties, defined as using a mobility aid or having trouble with standing, walking, or climbing stairs, have been shown to be at the highest risk of obesity [6]. In the same study, individuals with severe cases of mobility difficulties, such as use of a wheelchair or scooter, were also less likely to attempt weight loss compared to those without disability [6].

Regarding disability-specific concerns, data regarding the risk of chronic disease is particularly well described in the spinal cord injury (SCI), stroke, and amputee populations. Obesity and cardiovascular disease are rapidly becoming the most common morbidities in individuals with SCI [7]. Physical inactivity can hasten functional decline in persons with stroke, as the resultant reduced cardiorespiratory fitness may also limit walking endurance [8, 9]. Common comorbidities observed in individuals with amputation include peripheral arterial disease, stroke, and diabetes, indicating that amputees have the potential to benefit even more so from physical activity and exercise [10].

Unfortunately, the same chronic cardiovascular diseases that result from physical inactivity in individuals with disabilities can lead to further disability and functional decline. For example, heart disease has been shown to correlate with limitations in functional activities like cooking, grocery shopping, and housekeeping [11]. Additionally, health-related quality of life decreases proportionately with the progression of congestive heart failure [12].

Individuals with Disability Engage in Less Physical Activity

In light of these findings, it is important to note that people with disabilities typically engage in less leisure time physical activity compared to the general population [4, 13, 14]. For example, in one large population-based study, 32.8% of adults ages 18–44 years with disability report minimal engagement in leisure time physical activity, compared to 47.7% of similar-age adults with no disability. Middle-aged adults ages 45–64 years show a similar trend, cited at 79.2% in adults with disabilities, compared with 65.9% of adults with no disability [4]. Moreover, adolescents with disabilities also participate in less physical activity compared to their nondisabled peers. Compared to girls without disabilities in 9th–12th grades, girls with disabilities reported fewer days of physical activity (defined by at least 60 min per day of exercise), 3.1 days per week compared with 4.5 days per week [15]. As an exacerbating factor, individuals with disabilities may be less likely to receive exercise counseling from their physicians [6]. In summary, it is becoming increasingly clear that the removal of barriers to enhance the participation of people with disabilities in physical activity for health promotion is critical.

Lower Rates of Employment Among Individuals with Disability

It is well known that individuals with various types of disabilities are more likely to experience barriers to employment when compared to the general population. In 2010, the employment rate for adults with disabilities was about half of the general population, 41.1%, compared to 79.1%, according to the US Census data [16]. Specifically, those who reported self-care disabilities had among the lowest rate of employment (19.9%), along with wheelchair users (18.3%) [16]. Additionally, people with severe disabilities were twice as likely to live below the poverty line as those without disabilities (14.7 compared to 8.4%) [16]. A person's level of education certainly influences employment status, as persons with disabilities with at least some college education also have the highest employment rate, cited as 52% in 2008 [13]. In this setting, it is important to note that being of a lower socioeconomic status is a risk factor for not engaging in regular physical activity [8, 17].

Factors that Influence Physical Activity and Sports Participation in Individuals with Disabilities

Participation in organized sports has been shown to result in numerous benefits for both adolescents and adults with neurologic disability. A cross-sectional study on adolescents and young adults (ages 16–25 years) with myelomeningocele found that sports participation was associated with enjoyment of exercise, perceived athletic competence, global self-worth, and social support from family [18]. Similarly, in a recent narrative review, adults with SCI who engaged in organized sports reported higher life satisfaction, reduced anxiety and depression, augmented community integration, and higher rates of employment compared with nonparticipants [19]. These findings highlight the importance of increased sports participation.

Many factors such as physical functional impairment, reduced vision, hearing difficulties, cognitive impairments, mental illness, and emotional disturbances are possible reasons for hindering an individual's ability and motivation to engage in regular physical activity [20]. A wealth of prior literature has explored various types of barriers that may impact participation, some of which will be outlined here and are presented in Table 30.1.

Table 30.1 Environmental, personal, and social barriers and facilitators to physical activity

Environmental barriers	Environmental facilitators
Getting to the fitness center	
• Ramps too steep • Lack of curb cuts • Blocked curb cuts • Insufficient parking • Obstructed travel • Bad weather • Poorly functioning wheelchair	• Accessible transportation • Assistive technology • Accessible parking spaces • Level or graded terrain • Good weather
Mobility around fitness center	
• Doorways too narrow for wheelchairs • Door handles not suited for individuals with reduced dexterity • Front desk not at eye level • No elevators • Inaccessible bathrooms • Narrow aisles between equipment	• Multilevel front desks to accommodate wheelchair users • Push-button operated doors • Nonslip mats in locker rooms • Ramp access to whirlpools and hot tubs • Zero-depth entry pools • Family changing rooms
Equipment	
• No adaptive equipment (i.e., arm cycle)	• Velcro straps for grips • Pool chairs • Equipment that accommodate wheelchairs
Outdoor exercise areas	
• Uneven playground surfaces • Rough terrain	• Smooth and non-sloped playground surfaces
Personal barriers	**Personal facilitators**
Physical	
• Personal medical illness • Limited strength or fitness	• Good health • Personal fitness or possessing required skills for activity • Pre-injury sports participation

(continued)

Table 30.1 (continued)

Personal barriers	Personal facilitators
Emotional	
• Lack of motivation or will • Fear of exercise • Negative perceptions of disability • Apprehension of attracting unwanted attention	• Desire to be fit and active • Fun and relaxation in sports • Gaining confidence through exercise • Competition and winning in sports • Motivation from observation of other disabled peers with higher functional independence
Knowledge	
• Not knowing how or where to exercise	• Introduced to integrated play environments
High costs	
• Travel, equipment, facility fees	

Social barriers	Social facilitators
Culture	
• Negative societal attitudes	• Heightened disability awareness of parents, peers, and staff
Programs	
• Lack of sports facilities • Lack of transition programs from rehab to community	• Availability of community-based programs and opportunities to be active, including summer programs
Peers	
• Lack of friends to participate with • Rudeness during interaction with others	• Positive encouragement from peers • Learning from peers experienced in adaptive sport • Social support from other peers with disabilities
Family	
• Parental concerns about the child's safety in exercise • Parents lacking knowledge of physical activity opportunities available for children with disabilities	• Parent and family support

Table 30.1 (continued)

Social barriers	Social facilitators
Staff	
• Not trusting the competence of exercise staff in fitness centers • Fear of physical harm to children with disability and legal implications	

Environmental Barriers and Facilitators

Environmental factors such as lack of accessibility of the built infrastructure and rough terrain of public spaces play a role in limiting physical activity engagement by people with disabilities. A longitudinal survey of 28 adult wheelchair users evaluated the barriers and facilitators to accessibility of various settings, demonstrating that the most frequent environmental barriers were issues such as lack of ramps, lack of curb cuts, insufficient parking, inaccessible bathrooms, and narrow aisles between exercise equipment [21].

Studies utilizing focus groups of people with disabilities have also revealed additional barriers to exercise such as doorways being too narrow for wheelchairs and a lack of elevators in fitness facilities. Ease of communication with fitness facility staff was also often limited due to the front desk being too high for wheelchair users. Furthermore, fitness facilities often lack adaptive equipment for individuals with physical or sensory impairments, such as upper body cardiovascular exercise equipment [14, 22]. Of note, similar focus groups revealed that environmental facilitators included fitness centers having ample accessible parking spaces, push-button operated doors, nonslip mats in locker rooms, multilevel front desks to accommodate wheelchair users, ramp access to whirlpools and hot tubs, and Velcro straps to help grip exercise equipment. Many people with disabilities also noted the benefits of having family changing rooms to allow dressing/undressing assistance from family or personal care attendants [14].

With regard to outdoor fitness facilities, the vast majority of playgrounds and nature trails often do not accommodate children and youth with disabilities [23]. Additionally, the trails in the majority of parks are frequently rough, uneven, and difficult to navigate for people with mobility-related disabilities. In response, the US Department of Justice, Civil Rights Division, and the US Access Board have developed accessibility requirements reflecting the tenets of the Americans with Disabilities Act (ADA) and the Architectural Barriers Act (ABA). Regarding accessibility of playgrounds, the 2010 ADA Standards for Accessible Design and the ABA Accessibility Standards both outline requirements to optimize accessible play. In certain areas, there has been greater progress with development of specifically designed adaptive playgrounds for children with disabilities. As an example, playgrounds with non-sloped and smooth play surfaces and ample turning space are easier to navigate for children who use wheelchairs [24]. A longitudinal study on the accessibility of 35 playground surfaces, conducted by the National Center on Accessibility in 2008, found that newly constructed playground sites with loose-fill wood fiber surfaces deviated the most from accessible standards (excessive running slope, cross slope, and change in level) within 12 months from installation and also presented the greatest challenge to move across the playground surface in a wheelchair. Of note, this longitudinal survey found that tile and poured-in rubber required less exertion from the standpoint of the wheelchair user. Hybrid surface system, where there is some type of loose-fill base covered by a unitary mat, was felt to be the most durable and cost effective [25].

Personal Barriers and Facilitators

Personal barriers can also limit engagement in physical activity and sports. Common barriers for children and adults with disabilities are personal illness, limited strength or poor physical condition, lack of will, and lack of motivation [21, 23]. Financial difficulties can also limit sports and exercise participation by people with disabilities as the costs for travel, equipment, and facility fees result in a high economic burden [8, 17, 23]. Lack of insurance coverage for the fees associated with community fitness facilities may also hinder participation. A survey-based study on women with physical disabilities and another on individuals with stroke both found that specific barriers to exercise included the cost of joining a fitness center and not knowing how or where to exercise [8, 26]. Similarly, a systematic review on children with disability noted that fear of exercise, lack of exercise knowledge, negative perceptions of disability, and attracting unwanted attention presented significant barriers [23].

Personal facilitators to engagement in physical activity and sport include good morale, good health, and personal fitness [21]. In a population of youth with disabilities, the desire to be fit and active, having fun, gaining confidence through exercise, possessing the required skills for exercise, as well as having an introduction to integrated play environments were personal facilitators [23]. Likewise, a survey of 76 adult Paralympic athletes found that fun and relaxation (78%), health and physical fitness (61%), and competition and winning (53%) were personal facilitators for initiating sports. Maintenance in sports participation was also influenced by health (76%) and competition (72%) [27]. In a population of individuals with spinal cord injury, pre-injury sports participation has been correlated with the earlier initiation of consistent sports participation post-injury as well as longer duration of participation [28]. Findings also emphasized the importance of early education with regard to sports opportunities, such as prior to discharge from formal inpatient rehabilitation.

Social Barriers and Facilitators

Many interpersonal and social factors also serve as barriers or facilitators to physical activity and sports participation. In a population of children with disabilities, unsupportive peers, lack of friends to participate with, and negative societal attitudes were notable social barriers to physical activity [23]. This trend was also noted in adults with SCI and wheelchair users, who noted that a perception of feeling patronized and other people's rudeness were significant barriers [21, 29]. Other barriers for children with disabilities can come from parents, such as their concern for the child's safety with physical activity or lack of parental knowledge of the available physical activity opportunities [23]. Furthermore, lack of trust in the competence of exercise staff at fitness centers can also serve as a barrier to exercise [26]. Concomitantly, fitness staff may have negative attitudes toward working with people with disability. For example, some fitness staff consider working with children with disabilities more difficult or are fearful of physical harm to children and resultant legal implications [23]. Lack of fitness facilities and limited availability of inclusive exercise and recreation programs were noted barriers in both children and adults with disabilities [23, 27]. Furthermore, there is a notable lack of transition programs from rehabilitation to the community setting for individuals with disability [23].

Conversely, social support, awareness, and education are common themes for facilitators to physical activity and sports in children and adults with disabilities. Awareness of inclusive recreation programs and availability of community-based programs are notable social facilitators for children with a disability. Additional social facilitators include parental or family support, positive encouragement from peers, and increased disability awareness of parents, peers, and staff [23]. Interviews of athletes with SCI also reveal that playing sports with peers provides social support and motivates individuals to achieve greater functional independence [29]. In fact, athletes with SCI often describe how their peers are valuable sources of information for how to get involved and gain skill in sports [28]. It is important to note that the recognition of the numerous barriers and facilitators to physical activity above can help serve as the basis for public health policy.

Public Health Response Aimed to Increase Physical Activity in Individuals with Disabilities

Numerous public health initiatives have been established in the United States to increase physical activity engagement and help deter the rising rate of obesity and chronic disease due to sedentary lifestyles. In this setting, various strategies have been employed in an attempt to recruit the participation and inclusion of people with disabilities. Generally speaking, public health programs are either (1) mainstream programs targeted toward the general population, yet inclusive of people with disabilities, or (2) specifically targeted to the disability population (Table 30.2). It is commonly accepted that the use of both strategies concurrently is an optimal strategy toward ensuring the maximum involvement of the disability community.

Integration of Disability into All Mainstream Programs

Several programs in various regions throughout the United States have adopted strategy number one—that is—the inclusion of people with disabilities within mainstream public health programs. One example is the Communities Putting Prevention to Work Program, which strives to create healthier living environments in 50 urban, rural, and tribal communities throughout the country. To meet this goal, one project focuses on ensuring safe and active transportation for

Table 30.2 Public health initiatives to promote health

Mainstream programs	Goals
Communities Putting Prevention to Work	1. Create healthier living environments (a) Safe and active transportation i. Safe Roads to School Program (b) Healthy food and beverages at schools (c) Resources for tobacco cessation (d) Tobacco-free environments
CDC National Center on Birth Defects and Developmental Disabilities	1. Promote inclusion of individuals with disability into CDC's mainstream public health programs (a) Ensure disability status as demographic variable
Healthy People 2020	1. Address health disparities of people with disabilities 2. Facilitate inclusion of people with disabilities in public health activities 3. Provide timely, appropriate healthcare services for disability population 4. Remove environmental barriers
Disability-specific programs	Goals
National Center on Health, Physical Activity and Disability	1. Collaborate with leading health advocacy organizations to build leadership and expertise around disability-specific issues 2. Promote inclusion of individuals with disabilities 3. Educate on obesity prevention programs 4. Promote physical activity for the aging population and individuals with stroke, spina bifida, Down syndrome, hemophilia, etc.
Disability sports-specific organizations	Goals
Special Olympic Healthy Athletes Program	1. Use local and international Special Olympic events for: (a) Health screening of athletes with intellectual impairment (b) Educating athletes on role of physical activity to promote health (c) Training health professionals on how to treat individuals with intellectual disability and reduce health disparities
Paralympic Movement	1. Provide sports clinics and educational programs for disability sport 2. Support development of future Paralympic athletes 3. Increase disability awareness 4. Create fully accessible sports venues and transportation systems in host city of Paralympic Games

pedestrians, bicyclists, and mass transit users to help promote physical activity. For example, the Safe Routes to School Program promotes walking or biking to school. Communities Putting Prevention to Work also collaborates with schools to provide healthy food and beverage options. Lastly, they provide resources on tobacco cessation and promote tobacco-free environments to help decrease secondhand smoking [30]. Although these initiatives may help all individuals in the community to be more active, eat healthier, and decrease secondhand smoking, it remains unclear to what extent people with disabilities are integrated into the programming.

Ensuring inclusion within mainstream public health initiatives may help increase the participation of people with disabilities more broadly.

For example, the Centers for Disease Control and Prevention (CDC) National Center on Birth Defects and Developmental Disabilities promotes the inclusion of individuals with disability into the CDC's mainstream public health programs, striving to ensure that disability status is a demographic variable to all relevant CDC policies, programs, and surveys [31]. Additionally, Healthy People 2020 also focuses a section on addressing the health disparities of people with disabilities and facilitating their inclusion in public health activities, in addition to providing timely, appropriate healthcare services and the removal of environmental barriers [32].

Disability-Specific Programming

Concurrently, explicitly targeting the community of people with disabilities with specific public health programming may better increase this population's participation in physical activity. One program that employs this strategy is the National Center on Health, Physical Activity and Disability (NCHPAD), funded by the CDC, which collaborates with leading health advocacy organizations to build leadership and expertise around disability-specific issues and promote inclusion of the individuals with disability [33]. NCHPAD provides education on obesity prevention programs and physical activity promotion for the aging population and for various conditions, including stroke, spina bifida, Down syndrome, and hemophilia, to name a few [33].

Adaptive Sports Organizations Extending Their Public Health Reach

Sports organizations with high visibility like the Special Olympic and the Paralympic Movement within the United States provide inherent opportunities to promote physical activity and healthy lifestyles through disability sport. For example, the Special Olympic Healthy Athletes Program uses local and international events as venues for health screening and education and has widespread reach as it operates in 170 countries [34]. This program provides health screening of athletes with intellectual disabilities, including evaluation of dental and oral health, hearing, vision, muscle strength, bone strength, foot health, and physical fitness [35]. Concurrently, the Healthy Athletes Program provides education on health promotion for athletes and trains healthcare professionals on how to treat people with intellectual disabilities [34]. This in turn helps address healthcare disparities, since these trained medical professionals have increased knowledge of people with intellectual disabilities and feel better enabled to have them as patients once they return to their respective communities. At the same time, the Healthy Athletes Program collects data from their health screens, which they then incorporate into their educational programs, and helps facilitate fundraising efforts [34]. For example, after the 2003 Special Olympic World Summer Games found a high prevalence of obese (30%) and overweight (23%) athletes, the Healthy Athletes Program focused its educational efforts around healthy eating and weight loss [35].

Since 2001, the United States Olympic Committee has worked with several organizations including National Governing Bodies/High Performance Management Organizations and Paralympic Sports Clubs to provide sports clinics and educational programs for disability sport, especially for military veterans and youth [36]. While also promoting sport and physical activity, Paralympic Sports Clubs support the development of future Paralympic athletes, with emphasis on six sports: cycling, track and field, swimming, alpine skiing, cross-country skiing, and snowboarding [36]. More broadly, Paralympic sport and the Paralympic Movement also heighten disability awareness and may positively influence societal attitudes and cultural perceptions regarding the athletic capabilities of persons with disabilities. The required infrastructure of the Paralympic Games often results in the creation of fully accessible sports venues and transportation systems, which remain useful for people with disabilities even after conclusion of Paralympic Games in a host city. For example, following on the legacy of the 2008 Olympic and Paralympic Games, Beijing now has far more ramps, 2834 low-floor accessible buses, and raised tile walkways in bus and train stations to support visually impaired travelers [37]. Consequently, individuals with disability, who often rely on public transportation because of difficulties with driving or financial restrictions, will now have easier access to the community, including fitness facilities and other sites of public accommodation.

Relevant Policy History

For many years, the US government has established legislation to ensure specific rights for individuals with disability related to universal access and equal opportunity to services, programs, and venues (Table 30.3). Dating back many decades, the Rehabilitation Act of 1973 was the inaugural piece of civil rights legislation specific to the disability community, protecting access to federally supported programs and services such as those coordinated by the US Department of Education and the US Department of Health and Human Services [38]. At the time of passage, Section 504 of the Rehabilitation Act also encompassed access to national parks and federally supported fitness programs, however excluding privately owned health clubs and gyms. Under Section 504, students with disabilities must have access to a "free and appropriate public education," including equal access to physical education and athletics [39]. Furthermore, a Federal Guidance Notification from the US Department of Education in January 2013 upheld Section 504 requirements for equal opportunity participation for students with disabilities in extracurricular athletics, club, and interscholastic (varsity) athletics in schools receiving federal funding at all educational levels [40].

Table 30.3 Legislation promoting universal access to sport and fitness opportunities

Legislation	Year established	Guidelines
Architectural Barriers Act	1968	1. Provides access guidelines to federal buildings and nonfederal facilities constructed with federal grants or loans
Section 504 of the Rehabilitation Act	1973	1. Equal access and opportunity for individuals with disabilities to the same programs, services, and venues enjoyed by all persons (a) National parks (b) Federally supported programs offering fitness opportunities (c) Privately owned gyms and health clubs are excluded
Americans with Disabilities Act (ADA)	1990	1. Bans discrimination on the basis of disability in employment and education 2. Ensures accessibility of newly built infrastructure and transportation systems (a) Entry ramps (b) Accessible bathroom facilities (c) Accessible locker rooms
Individuals with Disabilities Education Act (IDEA)	1990 (reauthorized in 2014)	1. Standardizes special education for youth with disabilities 3–21 years of age 2. Includes participation in physical education
US Department of Education Federal Guidance Notification	2013	1. Ensures equal access to extracurricular athletics, club, and interscholastic (varsity) athletics in schools receiving federal funding at all educational levels
Maryland Fitness and Athletics Equity for Students with Disabilities Act	2008	1. Ensures access to public school interscholastic athletic programs for youth with disabilities in Maryland (a) Equal opportunity to participate in physical education (b) Equal opportunity to try out for athletic programs 2. County schools must provide reasonable accommodations to allow participation to the fullest extent possible 3. County schools must provide alternative physical education and athletic programs (i.e., adapted sports or unified sports)

Subsequently, the Americans with Disabilities Act (ADA) was passed in 1990, prohibiting discrimination in education and employment on the basis of disability and promoting universal access to elements of the built infrastructure and transportation systems in both public and privately owned environments [41]. Related to physical activity and sport, specific regulations under the Department of Justice Civil Rights Division (DOJ) and Department of Transportation (DOT) guarantee equal access to boating docks, golf courses, swimming pools, and other sporting facilities [42]. The ADA also requires newly constructed fitness facilities to be accessible to individuals with disabilities. For example, each facility must have entry ramps and accessible bathroom facilities within locker rooms.

The Individuals with Disabilities Education Act of 1990 (IDEA), reauthorized in 2004, established guidelines for special education for youth with disabilities 3–21 years of age and specifically includes participation in physical education [43]. In order to carry out this mandate, there are physical education instructors who are trained in adaptive methods to integrate youth with disabilities into physical education programs throughout the country [43].

There are also local laws at the state level regarding access to school-based sports. For instance, the 2008 Maryland Fitness and Athletics Equity for Students with Disabilities Act stems from a 2005 lawsuit by Tatyana McFadden against the state of Maryland. McFadden is a wheelchair racer and Paralympian who practiced and traveled with her high school track and field team, but was not allowed to become a full, point-scoring member or race alongside able-bodied peers during events. She and her mother filed a lawsuit against the Howard County Board of Education in Maryland, alleging discrimination. Subsequently, a Maryland judge found the school system in violation of Section 504 of the Rehabilitation Act of 1973 [44]. Thereafter, the passing of the Maryland Fitness and Athletics Equity for Students with Disabilities Act ensured that youth with disabilities in Maryland have equal access to public school interscholastic athletic programs, including physical education and sports. This also requires school systems to provide reasonable accommodations to allow participation or provide alternative programs like adapted sports [45].

Future Considerations

Many disparities and limitations in access to physical activity still exist for individuals with disabilities, even though society has changed dramatically over the past several decades. However, there is still far more to do (Table 30.4) to limit the disparities. Although the above existing laws certainly serve to expand disability access to physical activity and sport, implementation of the law still requires improvement. For example, many, if not most, communities have yet to comply with the 2013 Department of Education Federal Guidance on including students with disabilities in extracurricular athletics. Looking forward, interscholastic athletic departments, such as at the high school and collegiate level, must expand their knowledge via training and collaboration with disability sports experts in order to learn effective strategies for compliance. Additionally, in many collegiate environments, athletes with disabilities are still primarily limited to club or intramural-level competition. This is now beginning to change. In January 2015, the Eastern College Athletic Conference (ECAC), a conference of the National Collegiate Athletic Association (NCAA), was the first to adopt an “Inclusive Sport Strategy,” enabling colleges and universities to integrate disability sport in various integrated as well as disability-specific sports settings. Thus far, sports integrated into the inclusive sports strategy are rowing, swimming, tennis, and track and field. ECAC plans to include goalball, sitting volleyball, sled hockey, and wheelchair basketball adaptive sports teams in the next few years [46].

Ongoing public health and sports programs should also acknowledge the particular environmental and socioeconomic barriers to physical activity for the disability community, as outlined previously. For example, accessible, subsidized shuttles could be provided to individuals with

Table 30.4 Examples of policy-based solutions for addressing disparities in sports participation

Disparity/limitation	Possible solution
Many students with disabilities are still not fully integrated in extracurricular activities (as required by 2013 Department of Education Federal Guidance)	1. Collaboration of interscholastic athletic departments with disability sports experts to learn effective strategies for compliance
Athletes with disabilities are primarily involved in club or intramural-level sports and not NCAA sports	1. Eastern College Athlete Conference Inclusive Sport Strategy (a) Integrate disability sport into NCAA
Lack of transportation to public fitness facilities	1. Provide accessible, subsidized shuttles to individuals with disabilities
Structural barriers to physical fitness	1. Provide grants to fund accessibility-related projects 2. Offer tax credits to facility owners who update their facilities to comply with the ADA Standards for Accessible Design
High retrofit costs to comply with ADA Standards for Accessible Design	1. Facility owners design and build facilities to be accessible from the beginning (a) Include accessibility as a line item in their facility budgets
Difficulties with the continuum of sports or physical activity participation	1. Refer patients to a Certified Inclusive Fitness Trainers within commercial fitness facilities after completion of inpatient rehabilitation 2. Introduce patients to disability sports while still undergoing inpatient rehabilitation 3. Ensure similar training equipment for Paralympic athletes at local fitness centers
High economic burden to maintain fitness for persons with disabilities	1. Team sponsorships to support disability athletic programs, perhaps through donations from major corporations 2. Subsidized participation fees
Social stigma and misconceptions of disability sport	1. Increase disability awareness through collaboration with leaders from the disability community, who can act as spokespeople and instructors. 2. Outreach programs to specifically recruit people with disabilities in public health programs 3. Increase public awareness through the Paralympic Movement

disabilities throughout the community in order to address the well-described barrier of lack of transportation to public fitness facilities. Similarly, to partially mitigate the structural barriers to physical fitness, specific grants could be utilized to fund accessibility-related projects or tax credits offered to facility owners who update their facilities to comply with the ADA Standards for Accessible Design [14]. Facility owners could circumvent the need for unnecessary retrofit costs by firstly designing and building facilities to be accessible and perhaps include accessibility as a line item in their facility budgets [14]. Subsidizing participation fees to fitness centers or recreational teams may also help to overcome socioeconomic barriers, and continued advocacy for insurance coverage of gym memberships, particularly for people with disabilities, may be helpful for those who experience economic hardship.

Moving forward, another distinct goal of the advocacy community is to facilitate lifelong fitness opportunities after inpatient rehabilitation has been completed. In part, this may be accomplished via a referral to a Certified Inclusive Fitness Trainers (CIFT) within commercial fitness facilities [47]. Early involvement in adaptive sports programs while the patient is still undergoing inpatient rehabilitation can also increase awareness of these sports and encourage post-rehabilitation engagement. This continuum of sports participation applies at both the grassroots and elite level. For example, Paralympic athletes often receive support during US-sponsored training events and competitions; however, they still require similar access to accessible training sites near their homes to maintain peak physical conditioning during the off-season. A Paralympic wheelchair track athlete without similar equipment at his/her local fitness center to continue their strength and conditioning program will likely decline in performance.

Striving to increase disability awareness also plays a vital role in enhancing sports participation and should follow the principle of the disability rights movement, that is "nothing about us, without us" [48]. This may be achieved by collaborating with leaders from the disability community to act as leaders, spokespeople, and instructors. Outreach programs to specifically recruit people with disabilities in public health programs may also help increase the number of program participants. Team sponsorships to support disability sports programs, perhaps through donations from major corporations, can also decrease the economic burden for persons with disabilities [14]. Lastly, the high-profile coverage of the Paralympic Movement amplifies the public awareness regarding the athletic capabilities of people with disabilities, helping to quell the negative social attitudes that may exist.

Conclusion

Many health disparities related to lack of physical activity and sedentary lifestyles are amplified within the disability community, including higher rates of obesity and metabolic or cardiovascular disease. Environmental, socioeconomic, and interpersonal barriers are persistent and serve to exacerbate these disparities. Government legislation and public health initiatives that promote inclusive physical activity attempt to alleviate these barriers. Yet many in the community, individuals with disabilities and administrators alike, are still not fully aware of these laws and policies, making full compliance difficult. The general public also has many misconceptions regarding the athletic capabilities of people with disability. Looking ahead, ongoing advocacy should strive to enhance the impact of legislation and public health practice in order to best serve the needs of this population.

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31 Controversies in Adaptive Sports

Luis Alfredo Guerrero, Shane Drakes, and Arthur Jason De Luigi

Introduction

The majority of athletes that participate in adaptive sports do so in an ethical manner and utilize medical resources to optimize nutrition, manage medical conditions, and comorbidities and to improve athletic performance. Performance improvement is achieved by the prescription of therapeutic services to improve strength, flexibility, range of motion, endurance, coordination, balance, and proprioception. There are, however, instances where athletes will use unacceptable methods of performance enhancement to have an advantage during competition. Some of these methods include doping, boosting, and the use of technological advances in adaptive equipment.

The World-Anti Doping Agency (WADA) has a set of policies and regulations that create a level playing field for athletes throughout the world. The agency enforces these policies and regulations with a monitoring program that adheres strictly to the World Anti-Doping Code. The "Code" is set of policies, rules, and regulations that foster consistencies in areas of testing, laboratories, therapeutic use exemptions (TUE's), the List of Prohibited Substances and Methods, and the protection of privacy and personal information.

Testing is a crucial part of an effective anti-doping program. The United States Anti-Doping Agency (USADA) has thorough program in accordance with the WADA International Standards that can test any athlete using urine or blood samples throughout the year without advanced notice. The results management process is done so in a manner that protects the rights of clean athletes, preserves the integrity of the competition, and also holds accountable those athletes that cheat by using performance enhancing drugs.

Doping in Adaptive Sports

Doping in sports has received much attention in recent years. The World Anti-Doping Code and WADA exist to promote a collaborative worldwide movement for sports free of doping and promote equity and fairness for athletes worldwide. This movement also aims to reduce exposure of athletes to health risks associated with doping.

As Paralympic sports have become more high profile and more lucrative, some disabled athletes have been seeking to improve performance by using banned substances, particularly in the

L.A. Guerrero, MD (✉)
Sports Medicine and Interventional Spine, Department of Physical Medicine and Rehabilitation, MedStar National Rehabilitation Network, Washington, DC, USA
e-mail: drlagmd@msn.com

S. Drakes, MD
Sports Medicine, St Michael, Barbados

A.J. De Luigi, DO
Department of Rehabilitation Medicine, Georgetown University School of Medicine, Washington, DC, USA

A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2_31

sport of powerlifting [1]. The banned substances are listed on the Prohibited List on the WADA website and are routinely updated. The list is extensive, and for the purposes of this chapter, we will discuss agents most commonly used in Paralympic sports.

Medications

Anabolic Steroids

Anabolic steroids are commonly used to increase muscle mass and strength. They are usually taken as pills, injections, or topical treatments. These agents also help the athlete recover quickly from training and competition, by reducing the amount of muscle damage that occurs. A newer class of designer steroids continues to be developed synthetically in an effort to prevent detection by monitoring authorities. These agents are specifically developed for athletes and have no approved medical use and have not been tested or approved by the Food and Drug Administration (FDA) and pose a significant health risk to the athlete. These risks include but are not limited to severe acne, tendinitis, tendon rupture, liver abnormalities, tumors, increased low-density lipids (LDL), decreased high-density lipids (HDL), hypertension, cardiovascular disease, aggressive behavior, rage, violence, psychiatric disorders, drug dependence, infections, and inhibited growth and development.

Taking anabolic steroids is not only prohibited by most sports organizations, it is also illegal, and drug enforcement agencies have pushed the majority of this industry into the black market creating additional health risks as these drugs are made in other countries or in laboratories that do not confer to government safety standards leading to impure or mislabeled products.

Testing has been effective at creating a level playing field. The first positive test results in Paralympic sports occurred at the 1992 Barcelona games with five athletes testing positive for banned substances. At the Sydney 2000 Paralympics, 10 powerlifters tested positive. At the Salt Lake City Winter Paralympics in 2002, a German cross-country skier, Thomas Oelsner, tested positive after winning two gold medals and was subsequently suspended for 2 years from all IPC events.

Beta-Blockers

Certain medications are considered illegal when used in certain sports. For example, beta-blockers are strictly prohibited in shooting sports. Beta-blockers are drugs that block norepinephrine and epinephrine from binding to beta receptors on nerves. By blocking these receptors, beta-blockers reduce heart rate and reduce blood pressure by dilating blood vessels. Beta-blockers also reduce anxiety, relax muscles, and reduce tremors. Athletes in sports such as archery and shooting use them as performance enhancement to reduce anxiety, thus enabling the individual to concentrate on the task more effectively. Adverse effects of beta-blockers include but are not limited to hypotension, bradycardia, impaired circulation, insomnia, heart failure, asthma, nausea, headaches, dizziness, and muscle cramps.

Medical professional needs to be aware of over-the-counter preparations and supplements that may contain beta-blockers. It is important to counsel the athlete to check the ingredients of all medications and supplements before their use. Any medication or supplement that does not have a label stating the ingredients on the bottle should not be used.

In the 2008 Beijing Olympic Games, double-medalist shooter Kim Jong-su tested positive for the beta-blocker propranolol and was disqualified from the Olympic Games and received a 2-year sanction.

Beta2-Agonists

Medications such as beta2-agonists are used to treat asthma and respiratory conditions. Athletes historically have also used them for performance enhancement in endurance sports. Research in athletes using inhaled forms of beta2-agonists failed to find a performance enhancing benefit. However, oral or injection preparations have been found to have anabolic properties that can help build muscles similar to anabolic steroids. WADA prohibits beta2-agonists and requires a therapeutic use exemption

(TUE), except for salbutamol in dosages under 1600 mcg in any 24 h period, formoterol dosages less than 54 mcg in any 24 h period, and salmeterol when taken according to manufacturer's instructions.

Beta2-agonists are medications that mainly affect the muscles around the airway. They work by telling the muscles around the airways to relax which leads to widening of the airways. In athletes with asthma, when the lung tissues become irritated, these muscles can contract leading to narrowing of the airways and subsequent breathlessness. Beta2-agonists in this situation will lead to easier breathing.

Beta2-agonists are grouped according to their duration of action. Short-acting and long-acting beta-agonists are used in multiple forms including pills, tablets, and intravenous routes, but the most common delivery mechanism is via inhalation. Short-acting beta2-agonists work within 3–5 min and last between 4 and 6 h and are effective at treating acute symptoms and are also used to prevent or reduce symptoms associated with known triggers such as exercise or cold weather. Long-acting beta2-agonists work within 20 min and can last up to 12 h and are primarily used as a maintenance drug.

Adverse effects of these medications include but are not limited to tachycardia, palpitations, muscle cramping, tremors, headaches, nausea, vomiting, and anxiety.

Blood Doping

Erythropoietin

Erythropoietin (EPO) is a naturally occurring hormone, secreted by the kidneys that control red blood cell production. Athletes have used EPO for many years to enhance performance, particularly in endurance sports. EPO stimulates the bone marrow to produce more red blood cells and therefore hemoglobin. A higher red blood cell counts translates to better oxygen transportation and higher rate of aerobic respiration. The faster the rate of aerobic respiration, the higher the level the athlete can work without using anaerobic systems which produce lactic acid and fatigue. EPO increases the blood viscosity that can lead to an increased risk of myocardial infarctions and cerebrovascular accidents.

Boosting in Adaptive Sports

Among athletes with a disability, there is a doping method unique to patients with spinal cord injury (SCI) which is known as "boosting." Boosting is the intentional induction of a state of autonomic dysreflexia with the aim of performance enhancement [2]. This leads to a dramatic increase in blood pressure prior to competition [3].

Autonomic Dysreflexia

Autonomic dysreflexia (AD) is a life-threatening phenomenon occurring in patients with SCI at or above the T6 level. It is caused by noxious and sometimes non-noxious stimuli below the level of the lesion [4]. Hypertension results and may be accompanied by several other symptoms and signs including bradycardia or tachycardia (especially during exercise), profuse sweating, flushing and skin warmth above the level of SCI, cold and pale skin and piloerection below the level of SCI, bronchospasm, Horner's syndrome, muscle spasm, restlessness, seizure, headache, and altered consciousness (Table 31.1). The most common triggering factors are bladder or bowel issues, but any visceral or somatic stimulus below the level of SCI can trigger an episode of AD [5]. As noted earlier, some athletes

Table 31.1 Symptoms and signs of autonomic dysreflexia

Hypertension	Horner's syndrome
Tachycardia or bradycardia	Muscle spasm
Profuse sweating	Restlessness
Flushing and skin warmth above the level of SCI	Seizure
Cold and pale skin below the level of SCI	Headache
Piloerection below the level of SCI	Altered consciousness
Bronchospasm	

intentionally induce a state of AD, and the common methods used will be discussed later in this section. Hypertension in these patients is taken as an elevation in BP of more than 20–40 mm Hg higher than baseline is regarded, as they usually have a lower than normal BP due to the SCI.

The underlying pathophysiology is thought to be the activation of the sympathetic nervous system by the triggering stimulus, leading to vasoconstriction below the level of SCI, leading to increased BP and the other symptoms/signs below the level of the lesion. Parasympathetic activity is triggered by the baroreceptors sensing the hypertension. Descending supraspinal inhibitory signals are blocked at the level of the SCI.

Management of AD involves sitting the individual upright, loosening/removing any restrictive clothing, and addressing the underlying trigger. Rapidly acting antihypertensive medications may be needed if BP remains elevated despite addressing the possible trigger. Monitoring should be continued to ensure that the episode has resolved.

Effect of Autonomic Dysfunction on Exercise Performance

In order to understand why athletes with SCI may seek to deliberately induce such a dangerous phenomenon, it is important to consider the physiological response to exercise in such athletes. Much is already known about the impairment in motor and sensory function that occurs as a result of SCI, but the impairments in autonomic function are not fully understood. Just as the motor and sensory impairments present in SCI vary according to the neurologic level of injury, the autonomic dysfunction also varies according to the neurologic level of SCI [6]. In the last few years, the international SCI community has developed an assessment tool to document remaining autonomic function after SCI [7]. It is worthwhile to review autonomic control of the cardiovascular system in able-bodied individuals and compare it with that in those with SCI.

The cardiovascular control center is in the medulla oblongata and receives projections from the cerebral cortex and hypothalamus. This system provides central autonomic control of cardiovascular function. The heart is under control of both the parasympathetic and sympathetic nervous systems, while the vasculature is primarily controlled by the sympathetic nervous system. Parasympathetic control of the heart is provided by the vagus nerve whose preganglionic fibers synapse with postganglionic parasympathetic neurons in ganglia on or near the heart. Supraspinal pathways provide descending sympathetic input to spinal preganglionic neurons mainly found within the lateral horn of the spinal cord at T1–L2. These neurons synapse with postganglionic neurons in the paravertebral sympathetic chain ganglia and these in turn synapse with the heart (T1–T5 segment) and blood vessels (T1–L2). Therefore, after any neurologic level of SCI, the cranial parasympathetic nervous system will remain intact, and the sacral system will always be involved. The sympathetic nervous system's involvement will depend on the neurologic level of injury and the autonomic completeness of the injury.

Cardiac output is the product of HR and stroke volume and is controlled by a complex array of mechanisms. In highly trained able-bodied athletes, cardiac output increases up to sevenfold during maximal exercise. Studies investigating the cardiac output response to maximal exercise in SCI found a less than twofold increase during maximal aerobic arm exercise in cervical SCI patients [8], and similar findings were found for submaximal functional electrical stimulation cycling exercise in cervical SCI [9].

The decreased cardiac output in cervical SCI is due to impairments in both stroke volume and heart rate (HR). In cervical SCI, there is no change in stroke volume compared to the resting state with either submaximal or maximal arm exercise [8]. This is attributed to reduced venous return caused by the inability to cause vasoconstriction of the splanchnic vasculature. In high-thoracic SCI, the stroke volume response to exercise is lower than in able-bodied individuals but not significantly so [9]; in low-thoracic or lumbar SCI, the stroke volume response is similar to that of able-bodied individuals [10].

Traditionally it has been thought that individuals with cervical SCI exhibit a maximum HR between 100 and 120 beats per minute (bpm), while those with thoracic or lumbar SCI exhibit a relatively normal maximal HR. The reduced HR response to maximal exercise in cervical SCI is attributed to diminished sympathetic activity to the myocardium and reduced circulating catecholamines [11]. However, it has been observed that some elite cervical SCI athletes have almost normal age-predicted maximal HR. A study found partial to fully functioning sympathetic pathways in some patients with neurologically complete cervical SCI, and there was a strong association between the degree of autonomic function and the maximum HR obtained during exercise [12]. Therefore, it appears that the response to exercise in SCI is dependent on the integrity of autonomic pathways and not just the level of injury.

Blood pressure (BP) is the product of cardiac output and peripheral resistance and is regulated at rests via sympathetic activity on the vasculature which controls the peripheral resistance. As exercise intensity is increased, cardiac output gradually contributes more to BP regulation. The balance between the two contributors to BP is controlled through hormonal and autonomic influences on the heart, vasodilatory substances released from exercising muscles and sympathetically mediated vasoconstriction [6]. In SCI, the BP response to exercise is compromised both due to loss of central cardiovascular control and loss of reflexive vasoconstriction. One study showed that individuals with cervical SCI were unable to maintain their BP during functional electrical stimulation (FES) cycling, while those with thoracic SCI could do so [9]. In another study, persons with low thoracic SCI showed increased BP in response to exercise, while those with cervical SCI exhibited decreased BP [13].

In able-bodied persons, elevated sympathetic activity constricts the splanchnic vasculature to redistribute blood to the exercising muscles [14]. In individuals with cervical SCI, loss of abdominal muscle tone increases abdominal compliance [15] and predisposes to splanchnic blood pooling. This combined with the lack of descending sympathetic activity leads to compromised blood volume redistribution during exercise. Portal vein flow during incremental arm exercise was shown to be unchanged in cervical and high-thoracic SCI and reduced in low (below T7) SCI and able-bodied controls, implying that those with high SCI are unable to redistribute blood during exercise [16].

Several studies have examined whether increasing BP affects exercise capacity and/or performance. One study used a 10 mg dose of and all participants had increased BP during exercise, but only 50% exhibited increased maximal oxygen uptake [17]. The same group of athletes were studied, while intentional induction of AD was done in the laboratory setting. Significantly increased peak HR, BP, circulating norepinephrine (NE) levels, oxygen uptake, and power output during exercise, along with 10% improvement in time trial performance, were found [18]. A more recent study of six elite athletes with tetraplegia demonstrated significantly increased peak HR and BP, circulating NE levels, maximal oxygen uptake, and peak power [19].

How Widespread Is the Boosting Phenomenon?

The obvious benefits to performance of competing in a dysreflexic state have led some athletes to use this during competition. Self-induced injury may be caused in several ways such as excessive tightening of leg straps, administering electrical shocks to the muscles, constricting the lower extremities or scrotum, fracturing toes, or clamping the urinary catheter to cause overfilling of the bladder [20]. A study investigated the incidence of boosting in Paralympic athletes as well as their knowledge regarding the practice. It was found that 56% of participant knew about boosting and 16.7% reported having boosted in the past. However, 48.9% of athletes considered it dangerous, 21.3% felt it was dangerous, and 25.5% thought it was very dangerous [21]. Although the number of athletes who admitted boosting was relatively small, there was a great need for more education about the practice and the dangers of it.

Short-term dangers of AD include increased BP, cardiac arrhythmias, pulmonary edema, cerebral hemorrhage, seizures, retinal hemorrhage, and metabolic problems such as hyponatremia, cardiac arrest, and death. Some of the stimuli used to induce this phenomenon can cause problems such as hydronephrosis, pyelonephritis, and skin infections. In terms of long term issues caused by AD, it is thought that elevated BP could accelerate atherosclerosis [20].

The Positions of the Governing Bodies of Adaptive Sports

Boosting is not prohibited by WADA although it is a method of performance enhancement comparable to other methods, which are on the prohibited. However, it has been prohibited by the International Paralympic Committee (IPC) since the 1990s, initially because of ethical concerns and the performance enhancement of the process. Since then, the IPC has recognized that it can be harmful to athletes and prohibits any athlete from competing while in a dysreflexic state, whether or not it was intentionally induced [22]. The IPC's Position Statement on AD and Boosting states that "A hazardous dysreflexic state is considered to be present when the systolic blood pressure is 180 mm Hg or above" (IPC Handbook 2009, Chap. 4.3). The current approach is to test an athlete's BP prior to competition and recheck 10 min later if the systolic BP $\geq$ 180 mmHg. If it measures $\geq$180 mm Hg at the recheck, the athlete will be withdrawn from competition. No athlete has so far tested positive for boosting at an IPC sanctioned event [3].

How Effective Is the Current Method for Detecting Boosting and Preventing Adverse Events?

There are a few issues with the current BP threshold the IPC has for diagnosing the "hazardous dysreflexic state" which leads to disqualification from competition. Research has shown that a performance-enhancing effect is present at a systolic BP of 140–160 mm Hg [18, 19]. Therefore, athletes who are boosting but don't reach the threshold will be allowed to compete with an unfair advantage. It has also been found that episodes of AD with BP <180 mm Hg have been associated with life-threatening complications such as cerebral hemorrhage, seizures, cardiac arrhythmias, cardiac arrest, and pulmonary edema [23]. Part of the justification for the current BP threshold is to avoid false positives caused by the physiological effects of warming up and pre-event anxiety or excitement [3]. To those athletes with autonomic complete SCI above the level of the origin of sympathetic innervation to the heart, these factors will not contribute to elevated BP [24]. At this point, however, testers are unaware which athletes have autonomic complete injuries, so it would be unfair to disqualify an athlete with an autonomic incomplete injury who has an elevated pre-event BP due to those aforementioned factors.

Future Approaches to Detecting Boosting

There are a few things that the IPC can consider in order to make the detection of boosting athletes easier and to help discourage athletes from boosting. Documentation of autonomic function using the method recently developed by the International SCI community [7] may help in the classification of athletes. If athletes are competing against others with similar autonomic function, this will create a more level playing field and remove the added motivation to boost that some athletes may have [25]. Another suggestion is the creation of a "BP passport" for each athlete so that a BP threshold can be developed for each athlete instead of a single threshold for all athletes [3]. This will enable the easier detection of athletes who are boosting but may not have a BP which has reached the current threshold of 180 mm Hg. This encourages a level playing field and also can prevent adverse advents during competition as a result of this dangerous practice.

Autonomic dysfunction is present to a variable degree in SCI and can vary even in individuals with a similar neurological level of injury. In order to compensate for the significant effect such dysfunction has on the exercise performance of those with cervical and high thoracic SCI, some individuals engage in the unfair and dangerous practice of boosting. Continued education of athletes and coaches and further research is crucial. The implementation of testing procedures which will maximally detect boosters and ensure fair play while reducing possible harm caused by this practice is the way forward to tackle this problem.

Equipment and Technology Issues

Advances in adaptive technology have led to controversy in the field of athletic competition. Athletes from countries with greater economic resources or athletes with a higher socioeconomic status will have access to more advanced technology. This can lead to a competitive imbalance between athletes [26]. These advances have also led to a controversy regarding competition between a disabled athlete and an able-bodied athlete. A great example of this was the controversy regarding Oscar Pistorius, the "Blade Runner."

Oscar Pistorius was the first double amputee to compete in the Olympics. After a 5-year fight to compete on equal terms at the highest level, he was able to compete against able-bodied athletes in the London 2012 Olympics. Oscar Pistorius was dominating the Paralympic sport of racing since 2004 using his first pair of Cheetah's. The Flex-Foot Cheetah, a prosthetic carbon fiber human foot replacement stores kinetic energy from the wearer's steps as potential energy and works like a spring, allowing the athlete to run and jump. After his win in 2004, Pistorius attempted to enter non-disabled international competitions, but was banned by the International Association of Athletics Federations, which said his prosthetic legs gave him an advantage over able-bodied athletes and he was told he could only compete in the Paralympics. His legal team fought this decision, and the ban was overturned in May 2008 by the Court of Arbitration for Sports. They found there was no evidence that he had an advantage over able-bodied athletes.

The controversy with this particular technology revolves around the kinetic energy stored in the flexible keel. The longer and more flexible keels will store the most energy which leads to a greater force of propulsion. The comparisons that have been made in the past regarding this stored energy and competition against able-bodied athletes did not take into account the increased energy cost associated with the limb-deficient athlete.

As technology continues to advance, the investigator must utilize appropriate methods in order to fully assess whether there is a competitive advantage to any advancement in technology.

Conclusion

Controversies in the field of adaptive sports medicine are vast and continually evolving. The areas of most concern are the ones that can lead to performance enhancement. Performance enhancement can be achieved through the use of approved and non-approved drugs, known as "doping." It can also be achieved by "boosting" in athletes with a spinal cord injury. And lastly, performance can be enhanced by the use of advanced adaptive technology and equipment.

Paralympic sporting organizations are working diligently to create a level playing field among their athletes. Resources are being used to develop new and better testing methods which can lead to earlier detection of cheaters. Better research methods are needed to assess whether any potential advantage exists in technology and equipment used by athletes.

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A.J. De Luigi (ed.), *Adaptive Sports Medicine*, DOI 10.1007/978-3-319-56568-2