THE ATHLETE WITH LIMB DEFICIENCY

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Sports participation has many psychological and physical benefits for individuals with limb deficiency. A limb deficiency may be simply defined as the absence of part, or all, of one or more limbs. A limb deficiency may be congenital or acquired from trauma or disease. As is true for all individuals with impairments, exercise forms a vital part of a successful rehabilitation process and integration into society. Many individuals and organisations are working diligently to improve the health and wellness of individuals with impairments by improving access to sports participation[1]. A primary focus of these efforts is to offer more opportunities for individuals with impairments to develop and maintain lifelong habits of engaging in physical activity. Research has shown that lower limb amputees are at higher risk for certain health issues compared with the general population. A decline in activity level after an amputation can lead to conditions such as obesity, contractures, diabetes, cardiovascular disease, low self-esteem and other medical and psychological conditions[2]. Studies of war amputees have found higher rates of ischaemic heart disease and diabetes mellitus, with one study reporting a 63% higher mortality rate from cardiovascular disease[2]. Experts investigating these associations have concluded that decreased physical activity is the cause of these health problems. Other reports have shown multiple health benefits to physical activity for amputees, including improvements in coping, mood, self-esteem and cognitive abilities, as well as in strength, cardiopulmonary endurance, muscle co-ordination and balance[3-5]. Therefore, it is important for physicians to help individuals with limb deficiency stay active.

However, barriers to participation in sport remain[6,7]. A survey of lower extremity amputees shed some light on these barriers. Sixty percent of respondents reported being active in sport or recreational activities. Respondents who reported lower activity levels generally had limb loss because of peripheral vascular disease. Reasons for not participating in sport included pain, embarrassment, insufficient training and lack of organised sports programmes. The activities that were most uncomfortable for this cohort were running and jumping. The most popular recreational activities reported were swimming and fishing[8].

Fortunately, the number of opportunities to participate in sport has been increasing. Numerous adaptive sports organisations have been developed around the world. The Paralympic Games are the largest competitive event for athletes with physical impairments and have included athletes with limb deficiencies since 1976. The goal of this article is to summarise the available information on biomechanics, prosthetic considerations, clinical evaluation and psychological issues pertinent to amputee athletes, in order to assist physicians in keeping athletes with limb deficiencies active.

THE BIOMECHANICAL CONSIDERATIONS OF ATHLETES WITH LIMB DEFICIENCY

In the setting of limb deficiency, the biomechanics of essentially all athletic

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activities will be altered in comparison to an able-bodied person. The intact limbs and trunk must compensate for loss of force production. Coaches, trainers and athletes benefit from understanding these biomechanical compensatory strategies when devising training programmes. Similarly, clinicians benefit from understanding these compensatory strategies because it will allow them to better diagnose, treat and prevent injuries in these athletes.

While a comprehensive review of the literature is beyond the scope of this article, highlighting some key studies will emphasise the important biomechanical concepts. Overall, the published biomechanics literature is relatively sparse and has focused primarily on athletes with lower limb deficiencies. There is a need for more biomechanical research on athletes with both upper and lower limb deficiencies. Research has shown that the energy cost for ambulation is greater for lower limb amputees than it is for able-bodied individuals. Higher levels of amputation are associated with increased metabolic demand. When compared to able-bodied individuals and controlling for walking speed, transtibial amputees expend between 9 and 33% more energy, and transfemoral amputees expend between 37 and 100% more energy. It has also been shown that when amputees and abled bodied individuals are allowed to select their own walking speed (i.e. 80 meters/minute for able-bodied individual versus 48 to 50 metres/minute for individuals with transtibial amputations), the amputee will expend the same amount of energy per unit of time, but, naturally, will cover less distance compared with a person without a lower limb deficiency[9].

Other studies have shown analogous differences during running. Individuals without a lower limb deficiency generate and absorb forces through foot, ankle and knee mechanisms, including pronation/supination, ankle dorsiflexion/plantar flexion and knee flexion/extension. Despite improvements in prosthetic knee componentry and the use of energy-storing feet, prostheses still do not provide as much cushioning effect as a normal limb. The greater forces experienced by the athlete who uses a prosthesis are transmitted to the stump, hip and trunk. Studies have evaluated mechanical energy characteristics, power output and joint movements in athletes with transtibial amputations compared to able-bodied runners. Researchers showed that athletes with transtibial amputations had greater contributions from the hip extensors for energy generation and energy absorption compared to controls[10,11]. A follow-up study using a similar protocol showed that transtibial runners transferred 74% more energy from the intact lower limb to the trunk during the swing phase of gait compared with controls11. Using different methodology, Buckley et al[12] found additional compensatory mechanisms and altered biomechanics in amputee runners. The amputees had an increased knee extension moment and accompanying increase in work at the residual knee compared with able-bodied controls.

Nolan and Lees also investigated the biomechanics of athletes with lower limb deficiencies. Their work further confirmed that athletes compensate for the functional loss of one or more joints by increasing net joint moments and power output on their intact side. The increased loads placed on the hip, trunk and contralateral lower limb of these athletes may have implications for the long-term health of the joints[13].

Nolan and Lees also studied long jumpers with lower limb amputations. As expected, they found lower approach speeds and shorter jumping distances compared with able-bodied jumpers. The technique used by jumpers with transtibial amputation was not very dissimilar from that used by able-bodied jumpers. However, transfemoral amputees jumped with a more upright trunk and used smaller hip and knee angles compared with able bodied controls and compared with transtibial athletes. The athletes with lower limb deficiencies compensated for the inability to gain as much vertical velocity during the compression phase of the jump by using greater hip range of motion during the extension phase[14]. These compensatory strategies could potentially lead to injury and again highlight the benefit of understanding the unique biomechanical considerations when training and treating athletes with limb deficiencies. Ever-changing patterns of sports participation and advances in prosthetic design will require ongoing study as they will change biomechanics, adaptive mechanisms and injury patterns.

Figure 1: A schematic showing an osseointegrated prosthesis in an individual with a transhumeral limb deficiency. A stem is surgically implanted into the bone in the residual limb. The component that transverses the skin is impregnated with anti-bacterial materials. The external part of the prosthesis is firmly clamped to the external part of the stem. This construct provides the individual with good pressure and vibratory feedback through the bone, improved fixation of the prosthesis to the residual limb, and fewer skin issues at the prosthesis/stump interface. Courtesy of Motion Control, Inc.

PROSTHETIC CONSIDERATIONS

Participation in sport by athletes with limb deficiency has benefitted greatly from advances in prosthetic technology. Many advances in prosthetic technology have in fact been driven by athletes who have challenged companies to improve high-performance prosthetic components. There are now prosthetic designs that allow for participation in sports such as ice climbing, paragliding, snowboarding and many others. The prosthetic evaluation should be tailored to the individual, their sport and their level of competition.

A few examples of sport-specific prosthetic considerations follow. However, it is beyond the scope of this article to provide a comprehensive discussion of prosthetic evaluations for all of the many sports that athletes with limb deficiency are now pursuing. For a skier with a transtibial amputation, optimal ankle positioning is achieved with a multi-axial ankle or a fixed ankle set in 15 to 25 degrees of dorsiflexion[15,16]. Athletes with higher levels of unilateral lower limb amputation typically ski without a prosthesis, using one ski and two outrigger poles. Some bilateral amputees will use a monoski with a bucket seating system and some will use two skis on two prosthetic legs. Many athletes do not utilise prostheses during swimming and prostheses are not permitted in international swimming competitions. However, there are prosthetic devices designed for recreational swimming and other water sports, such as water skiing. There are several adaptations available for cycling enthusiasts. One simple adaptation is use of a wider bicycle seat to improve balance, particularly if an athlete is pedalling with just one leg. For athletes who pedal with a prosthesis, special componentry allows the prosthetic limb to clip directly to the pedal or for upper limb deficiency, to the handlebar[15].

A prosthetist well versed in sports prosthetic technology is the best source for information about the rapidly changing technology available to amputees. The amputee's needs, desires and goals should be outlined and balanced with the cost of the prosthesis. An intelligently designed prosthesis can sometimes be used for both sports and activities of daily living. Often, however, the sports prosthesis is tailored specifically for a given sport and is not used for daily living activities or for other sports. If an athlete uses a prosthesis for activities it was not designed for, it can result in injury or device failure.

Ongoing advances in prosthetic technology will present a new set of medical challenges for athletes and health professionals in the future. One active area of development is osseointegrated prosthetics, in which a metallic stem is surgically and permanently affixed directly to bone in the residual limb, with part of this component passing through the skin, allowing for the secure attachment of the prosthesis to the stem (Figure 1). It can be anticipated that sports participation with osseointegrated prostheses will raise concern for peri-prosthetic fractures and infection at the skin/prosthesis interface. Another active area of research is neurally integrated prosthetics, in which a bionic prosthesis receives and sends complex signals to nerves in the residual limb via multi-channel micro-arrays that are surgically implanted in the nerves. The impacts of neurally integrated prostheses on safety and sports competition is not yet known. Further advances in energy storing and energy releasing prostheses will continue to result in improved athletic performance. Although it is outside the scope of this article, readers should anticipate future discussions among sports experts on the topic of when does the use of prosthetics confer an unfair competitive advantage to

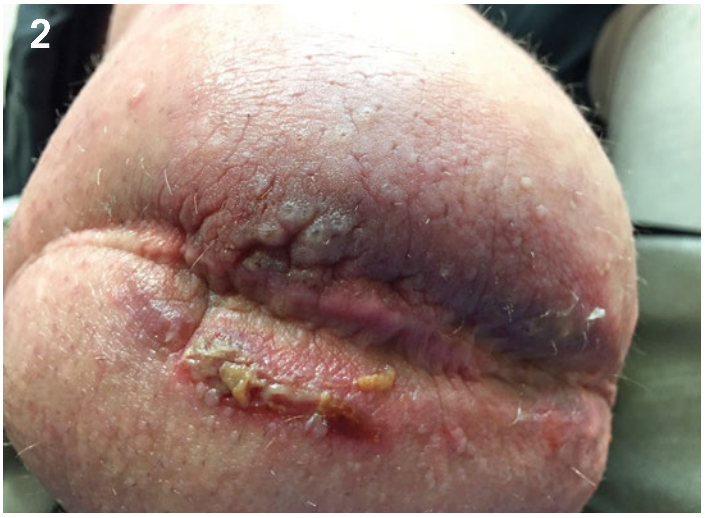

Figure 2: An irregular distal stump with a central indentation resulted in a difficult prosthetic fit. The raised white plaques above the indentation are examples of verrucous hyperplasia secondary to friction. Below the indentation is moderate skin irritation with yellow exudate and surrounding erythema, also due to friction. Courtesy of Colby Hansen, MD teaching files.

Figure 4: Surgery following a traumatic below knee amputation left the individual with a "dog ear" abnormality at the distal, lateral aspect of the stump. The dog ear is extra tissue which results from imperfect contouring of the skin and soft tissues at the time of surgery. When the individual began running with a prosthesis, there was abnormal rubbing at the dog ear, which resulted in skin breakdown. Courtesy of Colby Hansen, MD teaching files.

Figure 3: Heat and friction at the interface between the prosthetic socket and the skin of the residual limb resulted in the wide spread red area, which is a contact dermatitis. The smaller red spots seen more distally in the residual limb are due to a fungal rash. Courtesy of Colby Hansen, MD, teaching files.

para-athletes compared with able-bodied athletes.

INJURIES AND ILLNESS IN ATHLETES WITH LIMB DEFICIENCY

Most adaptive sports injury epidemiology studies have not focused specifically on athletes with limb deficiency, but instead include athletes with various physical impairments. One study found that injury rates among adaptive skiers was the same as among able-bodied skiers, but that the injury types were different. However, this study did not differentiate injury rates by type of disability[16]. Data on athletes with disabilities competing in summer sports from the Athletes with Disabilities Injury Registry found injury rates of 9.3/1,000 athlete exposures. This is similar to injury rates in many able-bodied sports[17]. Recent studies of injury epidemiology have found higher rates of injury among Paralympic athletes compared with Olympic athletes, but the Paralympic and Olympic studies used somewhat different methodologies[18-22].

Nyland, et al investigated the different types of injuries sustained by athletes with disabilities participating in the 1996 Atlanta Summer Paralympics. One notable difference was that athletes with limb deficiency sustained more ankle injuries than athletes with other disabilities[23]. A study by Ferrerra and Peterson evaluated injury patterns in wheelchair and ambulatory athletes. In contrast to wheelchair athletes who primarily experience upper limb injury, ambulatory athletes (amputee, visually impaired and cerebral palsy) more commonly experience lower limb injury[17]. Among amputees, athletes with upper limb deficiencies tend to have more cervical and thoracic spine injuries whereas athletes with lower limb deficiencies have more lumbar spine injuries. Klenck speculated that the greater incidence of thoracic and cervical injuries among athletes with upper limb deficiency was due to balance issues, while the greater incidence of lumbar injuries among lower limb amputees was due to excessive lumbar spine lateral flexion and extension[6].

Overuse injury patterns are also commonly seen in this population of athletes. The intact limbs are at risk for plantar fasciitis, Achilles tendinopathy, stress fractures and upper extremity overuse injuries from using crutches. Osteoarthritis of the hips and knees is another concern in athletes with lower limb amputations due to altered loading patterns. Studies have shown that amputees have an increased prevalence of OA in the contralateral knee compared with able-bodied persons. However, whether participation in sport increases this risk is not known[13,24]. This limited body of epidemiologic literature informs us that injury prevention programmes should include careful monitoring of training programmes, maladaptive compensatory mechanisms and improved protection of areas at risk for impact and stress[25].

Any physician caring for athletes who compete with prostheses need to be familiar with the common conditions seen at the stump/socket interface[26]. Many factors contribute to these conditions, including the high demands of sport participation, heat, sweating, friction, stump swelling, poor prosthetic fit and an irregularly shaped residual limb. Some of the common stump skin conditions seen include rash, verrucous hyperplasia, heterotopic ossification, swelling and limb pain due to pressure, friction, neuroma formation and phantom limb pain. Examples of some of these conditions are shown in Figures 2 to 4.

CLINICAL EVALUATION OF THE ATHLETE WITH LIMB DEFICIENCY AND ADVICE FOR TEAM PHYSICIANS

It should not be assumed that an athlete with limb deficiency cannot participate in any given sport; nor can it be assumed that all amputees are safe to participate in all sports[17]. For competitive athletes, a formal pre-participation sports evaluation should be conducted in the same manner as for able-bodied athletes, with additional attention given to the issues reviewed in this article[27]. Among the many factors that should be considered include medical conditions, level of competition, condition of the residual limb, type of sport, adaptive and protective equipment, psychological maturity and the inherent risks of injury in that sport[27,28]. The clinician must keep in mind that some injuries have greater functional consequences for amputees than for other athletes. For example, a high jumper with a lower limb deficiency who sustains an Achilles tendon rupture will be more limited in all activities compared with a wheelchair athlete or an able-bodied athlete with the same injury.

A comprehensive evaluation of the amputee athlete should also include assessment of their prosthetic history, issues with skin breakdown, stump pain and prior injuries. The stump should be inspected and palpated to look for skin changes, insensate areas and for its ability to withstand the increased stresses of sports activity. Proper prosthetic fit can decrease the risk of complications, but athletes who use a prosthesis remain at risk for complications.

Athletes with congenital limb deficiencies may have additional deficiencies in muscles, bones, soft tissues and ligaments that are not readily apparent. For example, some individuals with congenital lower limb deficiency also have deficiency of the anterior cruciate ligament[29]. For children who acquire an amputation, overgrowth of the residual limb in the skeletally immature athlete may lead to problems with prosthetic fit, skin breakdown, soft-tissue infections and osteomyelitis. These complications sometimes require periodic residual limb revisions until skeletal growth is complete[30].

Finally, clinicians should keep in mind that athletes with limb deficiency may have alterations in bone health which can affect sports participation. There have been case reports of residual limb fractures during competitive running that have been attributed to osteopenia. Although not widely accepted, some have proposed obtaining a DEXA scan prior to beginning impact sports[31]. More investigation into the natural course of bone loss following amputation and identification of distal limb bone density reference values is still required.

With few exceptions, such as issues specific to the stump, the clinical evaluation of injuries in athletes with limb deficiency is not inherently different than the evaluation of able-bodied athletes. As previously mentioned, athletes with limb deficiencies are participating in an increasingly diverse number of sports. Additionally, athletes partially compensate for limb deficiency using adaptive mechanisms. Such adaptations are dependent on the nature of the limb deficiency and the

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demands of the sport. These two factors also influence injury patterns. An improved understanding of injury patterns in athletes with limb deficiency will assist clinicians in diagnosing and treating injuries, as well as with designing safe training and rehabilitation programmes.

PSYCHOSOCIAL ASPECTS

Many of those living with disability face numerous barriers in their everyday life, including challenges with independent living, employment, relationships and participation in social activities. These barriers place them at risk for social isolation. Sports participation is an important part of both the psychological and functional rehabilitation of individuals with limb loss. Sport imparts psychological benefits including healthier perspectives on community reintegration, independent living, employment and social interactions. Furthermore, participation in sport and other recreational activities improves self-esteem, quality of life, overall health, self-efficacy, feelings of empowerment and motivation for continued involvement[3,5,30,32-35].

Individuals with congenital limb deficiency may have different psychological profiles compared with individuals with acquired limb deficiency. Children with congenital limb deficiency tend to have similar body image, ego and self-identity as those without a physical impairment. Some individuals with acquired limb deficiency experience more depression, anxiety and anger, which result in maladaptive coping mechanisms[35]. Understanding the psychological issues facing athletes with limb deficiency will allow for early recognition and counselling of personal conflict that might impair sports performance or daily coping strategies.

CONCLUSION

A vital part of rehabilitation and integration into society is participation in recreational and sports activities. Due to changes in attitudes and more sophisticated prosthetic technologies, a greater number of individuals with limb deficiency are participating in a wider variety of sports than ever before. Exercise benefits these individuals in many ways, including their physical health, mental health and coping strategies. Individuals with limb deficiency who participate in sport report improved social interactions, independent living skills and overall quality of life. Clinicians can assist individuals with congenital or acquired limb deficiency by encouraging sports participation, maximising prosthetic utilisation and breaking down barriers to sports participation. Clinicians will be better able to help athletes accomplish their goals if they possess an understanding of the unique biomechanics and injury patterns in different adaptive sports. Clinicians working with limb-deficient athletes should take a multi-disciplinary approach, consulting with coaches, trainers, prosthetists, physical therapists, recreation therapists, and sports and rehabilitation psychologists to facilitate successful sports participation. Finally, athletes with limb deficiency should be made aware of the many sports organisations and resources that are available for those who wish to pursue recreational and competitive sports activities.

References available at
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