Chapter 21

LOWER LIMB PROSTHETICS FOR SPORTS AND RECREATION

JOHN R. FERGASON, CPO*; AND PETER D. HARSCH, CP†

*Chief Prosthetist, Department of Orthopaedics and Rehabilitation, Brooke Army Medical Center, 3851 Roger Brooke Drive, Fort Sam Houston, Texas 78234

†Chief Prosthetist, C5 Combat Care Center Prosthetics, Naval Medical Center San Diego, 34800 Bob Wilson Drive, Building 3, San Diego, California 92134

INTRODUCTION

The value of sports and recreation continues to be a primary motivational factor for many service members with newly acquired lower limb amputations. Whether they were competitive prior to their amputations or not, they will become competitive to overcome their current physical limitations. The background and demographics of an active duty service member differ from the demographics of the majority of new civilian amputations that occur each year. Unlike the general population, every service member is preconditioned to train and work to pass mandatory physical fitness tests. Contrary to an elective amputation secondary to disease, trauma amputees have no time to prepare or process what it will be like to function with limb loss. They must be encouraged to challenge themselves to achieve new skills in activities that are unfamiliar to them that may be more appropriate to their new body, as well as continue to participate in their favorite sports. An informative survey conducted with disabled competitors in the 1996 Paralympic Games showed no mean differences in the results obtained in Goal Orientation, Competitiveness, and Desire-to-Win Scales when comparing men and women, onset of disability, adolescents and adults, and severity classifications.[1] This may suggest that the healthcare team does not have reliable predictors for who will excel; therefore, all competitors should be given the same opportunities. Participation in sports and recreation is universally beneficial not only for the demographic of an active duty service member, but also for the general population. Several publications[2–4] have made recommendations regarding the efficacy of regular physical activity to reduce disease concerns. Inactivity also increases the risk of many physical pathologies[5,6] and is the second most costly risk factor in cardiovascular disease.[7]

Physical activity has many specific benefits for the disabled population, including a decrease in self-reported stress, pain, and depression, as well as a general increase in the quality of life.[8] Participation in physical activity has shown a positive relationship with improved body image for many amputees.[9] For many active duty service members, the desire to continue in the Armed Forces is correlated to their physical ability to return to their previous military occupational specialty. Amputation of a lower limb does indeed constitute a major disability that can lead to functional and professional incapacities.[10] A commonly referenced survey (Kegel, 1985)[11] revealed that lower limb amputees had a strong interest in participating in sports and recreation. A majority of respondents indicated that their quality of life could be enhanced if the prosthesis did not limit their ability to move quickly and run.[11] A more recent survey showed that the 20- to 39-year-old age group had a similar distribution of interests between high-, moderate-, and low-energy-level activities; the survey reported a high ability to perform these activities while using a prosthesis.[12] This information suggests that the prosthesis is no longer the primary limiting factor when participating in desired activities. Given the opportunities for participation in sports that are currently offered to injured service members, the demand for new, innovative prosthetic designs is challenging the clinical and technical expertise of the prosthetist.

No artificial limb can replace what is lost in the trauma of conflict. However, aggressive rehabilitation and appropriate prosthetic provision will enhance the ability of injured individuals to pursue athletic activities once again. Understanding the biomechanics of the sport and the physical characteristics of the remnant limb are the first steps in determining what a prosthesis can provide. The following sections present principles involved in the design of prostheses suitable for sports and recreational activities.

WHEN TO PROVIDE A SPORTS-SPECIFIC PROSTHESIS

Because of the unique, comprehensive nature of military rehabilitation programs, high expectations are instituted early. Goal setting can be started by using the physical training fitness test as standard if the patient wants to remain on active duty. Encouragement from other patients with similar injuries can also be a significant motivating factor in the pursuit of recreational activity.

In addition, the general public has a heightened sense of awareness of the challenges involved in disabled sporting activities. Competition such as that seen in the Paralympic Games has gained wider exposure and has demonstrated that high-activity goals are attainable. Although world-class athletes seen in the Paralympic Games are true inspirations, most individuals will not pursue this level of activity. Exposure to a variety of sporting activities is a more effective method to peak the interest of the injured and even to open up new possibilities for recreation or competition.

The prosthesis optimized for recreation is finely tuned both to the specific function required and to the capabilities of the user. Realistic goals should be set in context to the overall physical capabilities of the individual. It is more encouraging to reach a small goal

Figure 21-1. Exiting the water using short, nonarticulated prostheses provides stability and function during the triathlon transition.
Photograph: Courtesy of Terry Martin.

quickly and then set more ambitious goals as incremental steps are attained. During performance of the physical evaluation and patient history, two of the most important considerations include (1) the mechanism of amputation and (2) the physical factors associated with the injury (eg, if the patient has experienced prolonged bed rest, rehabilitation must begin with a focus on the deconditioned status). The polytrauma nature of military injury often complicates the intensity of the rehabilitation because the patient has not experienced any significant activity since the injury. For example, in patients with compromised skin and associated diminished sensation, excessive skin loading in early weight bearing can lead to ulcers and an interruption in the ability to progress in ambulation skill.

While weight-bearing capability is being established, a comprehensive program of physical rehabilitation should be in progress. In one study on physical fitness, amputee test subjects were significantly deconditioned when demographically matched to able-bodied subjects. After an endurance training program was completed, there was no significant difference from the able-bodied subjects, showing that individuals with limb loss are able to recover from a poorly conditioned state.[13] The patient must be educated to understand that the primary key to successful participation in sports is a combination of preparatory physical training and appropriate prosthetic design. The prosthesis is merely a tool that plays an increasingly important role in maximized performance once strength, stamina, and skill progress.

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 on entry (Figure 21-1). In competition, the International Paralympic Committee

Figure 21-2. Bilateral transtibial amputee preparing for competition in the 2004 Paralympic Games.
Photograph: Courtesy of the US Paralympics, Colorado Springs, Colorado.

governs the use of assistive devices in the water. All prosthetics are removed prior to competition (Figure 21-2). The International Amputee Soccer Association requires that participants use bilateral forearm crutches with at least one amputated limb without a prosthesis. In these instances, it would be counterproductive for high-level competition to train with a prosthesis when it cannot be used in the competition. In contrast, the Paralympic alpine disciplines allow athletes with single leg amputations to choose use of a single ski, outriggers, or prostheses; however, athletes with arm amputations usually compete without using poles.

When prostheses are not worn, it is advisable that amputees wear some form of protection on the residual limb. It can be as simple as using the liner that is worn with the prosthesis. If increased protection from high-impact falls is needed, a custom limb protector can be fabricated.

GENERAL-USE 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 amputee 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—required during everyday ambulation can suffice for many recreational activities. Careful choice of the prosthetic foot allows the amputee to walk faster and achieve a more equal step length on both sides, thus facilitating recreation and routine walking.[14] The 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 amputees find it difficult to accurately report their activity level versus measured activity level, the clinician does not have to rush into sports-specific limbs during the early stages of rehabilitation.[15] Once the amputee 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.

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- and cost-effective than multiple individual prostheses.

SKIN TOLERANCE TO HIGH ACTIVITY

Identification of the functional demands the activity will place on the residual limb will help determine the design of the prosthetic socket. A prosthesis cannot fully replace complexities of the human leg, such as providing dynamic shock absorption, adaptation to uneven terrain, torque conversion, knee stabilization, limb lengthening and shortening to diminish the arc of the center of gravity, transfer of weight-bearing forces, and reliable weight-bearing support.[16] The significant difference in the activity is the nature and amount of impact and shear that will be placed on the residual limb. Long-term monitoring of ambulatory activity has indicated that our assumptions about the definition of high-activity level may not be correct.[17] Some sports (eg, running) require quick movement and many steps for a limited amount of time, whereas other sports (eg, golf) require many more steps over a period of several hours. The sports of running and golf could be considered high-activity levels, although with different durations. Understanding the functional demands is even more important. The runner's prosthesis must absorb the impact of loading response, support body weight through midstance to allow a long stride length on the sound side, and provide a measure of propulsive thrust at the end of stance. The golfer using a prosthesis endures long time periods of standing; maintains overall stability when twisting during swings; and ambulates safely over uneven terrain, slopes, and inclines.

Once the demands of the activity are understood, a careful evaluation will identify the weight-tolerant regions, as well as the skin sensitivity of the limb. A simple 10-g monofilament used to test foot sensation can be used to identify regions of the limb that lack protective sensation. This information should be relayed to the patient so that the individual has a full understanding of the importance of periodic visual skin evaluation during at-risk activity.

The greater the shear forces generated with a prosthesis, the lower the pressure required to cause tissue breakdown.[18] The cyclic shear stress that inevitably occurs within a prosthetic socket can cause a blister to form within the epidermis or can create an abrasion on the skin surface. When there is adherent scar tissue present, which is common following traumatic amputations, shear stress adjacent to the area results in skin tension that can cause blanching or even cell rupture.[19] Investigation of an instrumented patella tendon-bearing prosthetic socket demonstrated that maximal pressure and resultant shear stresses shifted locations between the loading phase of stance and the latter phases of the gait cycle.[20] This is a result of the dynamic movement of the residual limb within the socket. The planar force coupling that results in these measurement differences will be increased as directional activity changes with variations in movement of the prosthesis during sports.

As the individual's activity level increases, the pressure and shear forces can easily rise to levels that cause soft-tissue damage. An increase in activity can also be associated with a rise in the incidence of skin problems.[21] Common skin problems associated with prosthetic use include ulcers, irritations, inclusion cysts, calluses, contact dermatitis, hyperhidrosis, and infections.[22,23] When these complications occur, medical management and prosthetic adjustments are often necessary. Controlled prosthetic use while treating ulcerations, for example, can still allow the patient to be ambulatory and the ulcer to heal satisfactorily.[22]

GENERAL ALIGNMENT CONSIDERATIONS FOR SPORTS

Several studies demonstrate that alignment is not as critical as volume change in affecting skin stress on the residual limb.[24–26] 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 (Figure 21-3). In these instances, either a special-use prosthesis or interchangeable components will be necessary. If the user intends to interchange components, education must be instituted carefully to protect the limb from misalignment.

GENERAL COMPONENT CHOICES FOR FORCE REDUCTION IN SPORTS

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.[27] For transfemoral limbs, special consideration should be given to the ischial tuberosity area and the proximal tissue along the socket brim. Patient comfort can be increased by the use of a flexible plastic inner socket supported by a rigid external frame. This combination maintains the structural weight supporting the integrity of the socket while increasing the range of hip motion from the flexibility of the proximal socket.

The heels of prosthetic feet can dissipate significant amounts of energy during loading.[28] Feet were 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 part of a foot/ankle/shin 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

Figure 21-3. Upright control while surfing is enhanced when using straight pylons on the transfemoral prosthesis. Photograph: Courtesy of Joseph Gabunilas.

quantitative kinetic or kinematic advantages in how someone walks, but pylons do show a force reduction during loading response and a report of increased comfort, particularly at higher speeds.[29,30] It is important to consider that, when negotiating stair and step descent, the transfemoral amputee 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.[31] Given the importance of minimizing transverse plane shear stress on vulnerable soft tissue, this component should still be considered even though it can match exactly to characteristics of the sound side.

Hafner et al[32] suggest that the development and recommendation of prosthetic feet without supporting evidence of their performance may be the result of conflicting or inconclusive results in the reported literature. There is a missing link between the scientific evidence and clinical experience of the medical providers. Although subtle changes in gait and performance parameters are not statistically significant, these differences are perceived by amputees to affect their preferences and perception of foot performance. Later studies do suggest that variations in prescription may allow for benefits such as greater propulsive impulses by the residual leg that contribute to limb symmetry.[33,34]

TRANSTIBIAL RUNNING

Prior to performing running activities, it is helpful to understand the running goals of the service member. If the primary desire of the individual is to jog for cardiovascular endurance, a slow jog occurs at about 140 m/min. At this speed, the heel has minimal effect because the middle portion of the foot becomes the primary initial contact point. Because the heel is minimally used or virtually eliminated as speeds increase to approximately 180 m/min in running, a specific running foot without a heel component may be advantageous (Figure 21-4).[35] Prosthetic limb kinematics have been shown to mimic this able-bodied data.[36] The running foot is very light and highly responsive. There is a significant amount of deflection on weight bearing that adds to the shock-absorbing qualities. A running shoe tread is adhered to the plantar surface to further reduce weight. If a

Figure 21-4. Running-specific foot modules are used to mimic natural running biomechanics.
Photograph: Reproduced with permission from ASI PHOTOS, Fort Worth, Texas.

Figure 21-5. Track-and-field sprint-specific feet are used for quick acceleration and high cadence speed.
Photograph: Courtesy of Peter Harsch.

decrease in speed occurs (eg, when jogging with intermittent walking), the heel will become more important and a more versatile utility foot should be chosen. If the amputee desires to sprint and short bursts of speed are the goal, a sprint-specific foot should be considered (Figure 21-5). In general, the sprint foot is designed with a much longer shank that attaches to the posterior of the socket. This gives 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. If 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. Because suspension is a key factor in movement and shear reduction on the limb, an airtight sleeve and expulsion valve can give the best limb stability.[37]

TRANSFEMORAL RUNNING

Design of a transfemoral running limb follows the same guidelines as previously discussed for the transtibial running limb. Component choices are based on defining the goal of jogging and sprinting. Foot choices and use criteria are identical for both transtibial and transfemoral limbs. The next decision involves whether to incorporate a knee or begin with a nonarticulated limb. Beginning without a knee is

Figure 21-6. Transfemoral runners can use a nonarticulating limb with a circumducted gait to increase stance stability and energy efficiency.
Photograph: Courtesy of Thomas F. Martin, Jr, and Anderson Independent-Mail, Anderson, South Carolina.

Figure 21-7. Transfemoral runner exhibiting a knee flexion running gait using a hydraulic single axis knee, sprint foot, and 20-degree angle bracket.
Photograph: Courtesy of Prosthetic Innovations LLC, Eddystone, Pennsylvania.

a viable option when stability is a concern or when suitable cardiovascular endurance has not yet been attained. Training begins with a circumducted gait to allow foot clearance in swing. If a patient intends to participate in distance running, a nonarticulated system eliminates the mental concern of inadvertent knee flexion and seems to be significantly less demanding for a longer run (Figure 21-6). When sprinting is the goal, use of a knee is generally recommended. There are several good choices available that use hydraulic control of flexion and extension resistance and that interface well with the sprint feet (Figure 21-7). The knees and overall alignment must be fine-tuned to the individual needs of the patient. Interlimb asymmetry has been shown to increase significantly when the transfemoral amputee runs. Therefore, special attention to alignment, component adjustments, and training is particularly important.[36,38] Maximum sports performance may require modified or even specialized components or significant deviations from standard alignment techniques to help improve interlimb symmetry and running velocity.[39]

CYCLING

Cycling is an excellent exercise that is nonweight bearing and indicated for those who may have closed-chain impact restrictions. Once proper fitting of the bicycle has been completed, the prosthesis will need some accommodations if more than recreational cycling is intended (Figure 21-8). For the transtibial amputee, knee flexion restriction must be minimized. Suspension systems that cross the knee, such as suction with gel sleeves, can be replaced with distal pin-and-lock options. If the sleeve is still preferred by the patient, choosing one that is preflexed and just tight enough to maintain a suction seal is adequate. The posterior socket brim is typically restrictive in full knee flexion. Providing an adequately low posterior brim to allow full knee flexion often will not comfortably support the limb during ambulation. This can be overcome by

Figure 21-8. Paralympic cyclist with a direct attached carbon fiber foot and shin system to enhance aerodynamic efficiency.
Photograph: Reproduced with permission from Brightroom, Inc, Fort Worth, Texas.

Figure 21-9. Transfemoral amputee exhibiting free swing from a seven axis knee with a direct attached carbon foot system.
Photograph: Courtesy of Coyote Design, Boise, Idaho.

designing a posterior brim that is removable for biking and replaced for ambulation.

The transfemoral amputee must be provided adequate clearance between the ischial tuberosity and the cycle seat. Careful socket adjustments in this region can usually provide a limb that is comfortable for limited ambulation and extended seat time (Figure 21-9). The knee choice 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. Choosing a knee component that is safe to walk on in a free swing mode will be helpful. For both levels of amputation, the foot stiffness can be increased to ensure maximum transfer of energy to the pedal. This will leave 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. Unilateral transtibial amputee cyclists have been shown to exhibit more pedaling asymmetry than the able-bodied population. This may be also related to foot stiffness, but was not shown to be statistically significant in preliminary data (Childers WL, Kistenberg RS, Gregor RJ, unpublished data, 2007).

ROCK CLIMBING

Rock climbing has increased in popularity in the past 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 locales. Commercially produced prosthetic feet are unsuitable for rock climbing because 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 (Figure 21-10). The foot should be shortened to decrease the torque and rotation that occur with a longer lever arm. The shape of the foot should be contoured to

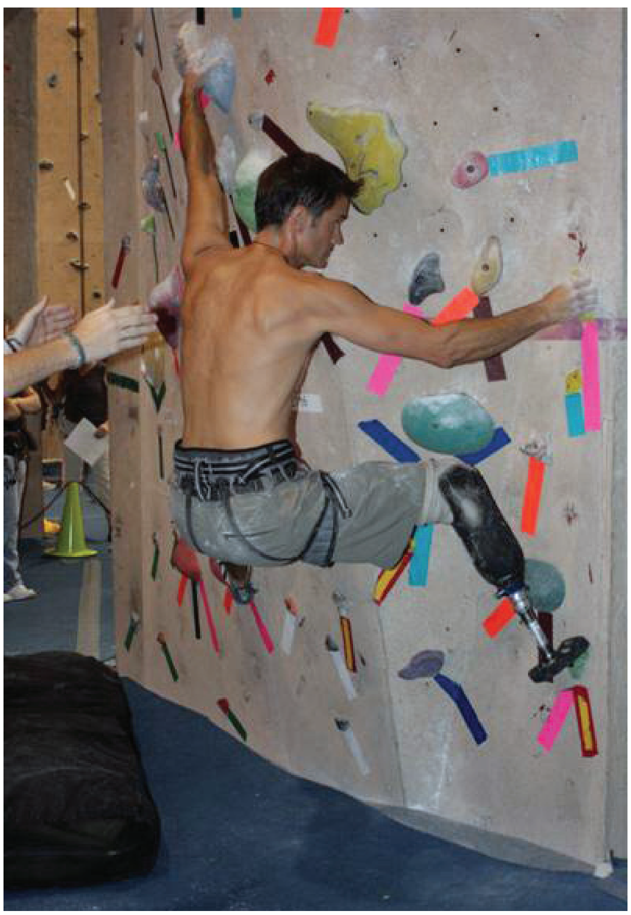

Figure 21-10. Custom foot module with spikes and Kevlar (Du Pont de Nemours and Company, Wilmington, Delaware) is used to increase traction while scaling an indoor rock-climbing wall.
Photograph: Courtesy of College Park Industries, Fraser, Michigan.

Figure 21-11. Wake boarding is made possible with sports-specific knees that provide stability with flexion- and extension-assisted support.
Photograph: Courtesy of Ed Rosenberger.

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 performance. Making the prosthesis easily height adjustable allows the user to optimize limb length for different types of climbs. If no prosthesis is used, limb protection should be provided.

WATER SPORTS

After running sports, water sports are the next most popular activities. Depending on geographical location, water sports may be more or less a part of the culture. Most prostheses will tolerate occasional and nominal exposure to moisture, particularly when protected under a layer of clothing. The everyday prosthesis should be made resistant to splashes that occasionally occur, especially when living in a wet climate. A specialized, waterproof design is necessary when the amputee will have regular exposure to salt water or freshwater, especially if complete immersion is intended (Figure 21-11). For the bilateral transfemoral patient, prosthetic devices are usually bypassed in favor of specialty seating systems that allow participation at the highest levels.[40]

WINTER SPORTS

The amputee interested in winter sports currently has an unprecedented opportunity for participation. For those interested in downhill skiing, most individuals with unilateral transtibial amputation continue to use a prosthesis (Figure 21-12). Although a walking limb can be adapted and used, a ski-specific alignment should be performed for the duration of the activity. 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 will attach 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. Unilateral transfemoral skiers will usually opt to use a single ski with bilateral forearm outriggers (Figure 21-13). The immense popularity of snowboarding has accelerated developmental designs for the transfemoral amputee. A recently released knee has been designed specifically for sports that require a loaded, flexed knee position. Snowboarders are in bilateral dynamic hip, knee, and ankle flexion as they negotiate the hill (Figure 21-14). This knee is adjustable and produces the weighted knee flexion necessary to snowboard successfully. The transtibial snowboarder needs additional dorsiflexion range and flexibility in the prosthetic foot.

Figure 21-12. Advanced dynamic sport knee builds energy during flexion and returns energy in extension to provide superior control for the transfemoral skier.
Photograph: Courtesy of SymbioTechs, USA LLC, Amity, Oregon.

Figure 21-13. Adaptive ski poles for the downhill skier replaces the need for a sports-specific prosthesis.
Photograph: Courtesy of Byron Hetzler.

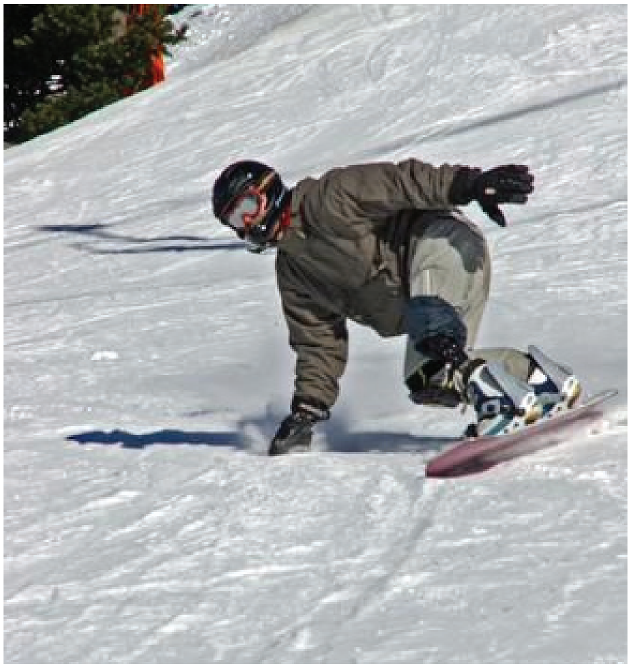

Figure 21-14. No additional adaptive gear is necessary for this transfemoral snowboarder when using this energy-storing prosthetic knee.
Photograph: Courtesy of Symbiotechs, USA LLC, Amity, Oregon.

Figure 21-15. Torsion control systems allow for proper swing mechanics for the amputee golfer.
Photograph: Courtesy of Michael Pack, Artificial Limb Specialists, Phoenix, Arizona.

GOLF

The longevity of potential participation in this sport may be a major factor in its popularity. Golf is a sport that can be entered into when one is quite young and often followed throughout a lifetime. A correct golf swing requires triplanar movements at the ankle, hip, and shoulder joints. Because prosthetic feet cannot duplicate the three-dimensional movement of the ankle, torque absorbers or rotational adapters can be introduced (Figure 21-15). Amputee 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. Studies have confirmed this fact and show improved hip and shoulder rotations, particularly in the left-sided amputee.[41,42]

HIKING

Activity that includes traversing uneven terrain (eg, hiking) requires consideration of a multiaxial ankle. This type of ankle allows the prosthetic foot to conform to irregular surfaces, thus reducing the forces transferred to the residual limb.

As the amputee 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 amputee will resist this knee flexion moment, increasing the forces on the residual limb within the socket. When aligning and adjusting a new prosthesis, the amputee should be evaluated on surfaces similar to those that will be encountered in the athletic activity limb. Perhaps even more significant than multiaxial feet and torque absorbers is the recent release of a motorized ankle. This type of ankle does not generate propulsive power, but rather senses electronically when the user is on an incline or decline. The ankle requires two strides to sense the orientation, then it will consequently plantarflex or dorsiflex the foot to ease the moments that are induced on the knee and the forces that act on the residual limb.

INJURIES AND LONG-TERM EFFECTS

With this focus on sports as an aspect of rehabilitation for the limb amputee comes an inherent increased risk of injury. Injuries for the disabled sporting community are similar to those for athletes without disabilities. Locations of the injury seem to be sports- and disability-dependent. Ambulatory amputee athletes more commonly have lower extremity injuries (eg, abrasions, strains, sprains, and contusions).[43] Spine and intact limb injuries are also common to the amputee.[44] Additional attention must be focused on the issue of depressive symptoms that are seen so commonly in conflict amputations. A correlation has been noted between depression and prediction of pain intensity and bothersomeness.[45] Amputees have also been shown to suffer from various comorbidities associated with biomechanical abnormalities.[46–49]

OTHER CONSIDERATIONS

Prescribing component recommendations that facilitate higher activities is typically based on the experience of the prosthetist primarily because of the lack of conclusive scientific evidence on these applications.[18] It is useful to clearly understand the functional and biomechanical demands of a specific sport when forming a prescription recommendation 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.

SUMMARY

The needs and preferences of the amputee should be clearly understood, and the functional demands of the activity should be determined prior to generating the prescription. Physical training status should be evaluated before intensive participation, particularly in sports unfamiliar to the participant. Early in the rehabilitation process, the prosthesis can usually be adapted to the activity and still be used effectively in therapy. As the amputee 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.

REFERENCES

1. Page SJ. Exploring competitive orientation in a group of athletes participating in the 1996 Paralympic trials. *Percept Mot Skills.* 2000;91:491–502.

2. Pasquena PF. National Disabled Veterans Winter Sports Clinic. *J Rehabil Res Dev.* 2006;43:xi–xv.

3. US Public Health Service, US Department of Health and Human Services. *Healthy People 2000*: *National Health Promotion and Disease Prevention Objectives*. Washington, DC: DHHS; 1991. DHHS Pub No. PHS 91-50212.

4. US Public Health Service, NIH Consensus Development Panel on Physical Activity and Cardiovascular Health. Physical activity and cardiovascular health. *JAMA.* 1996:276:241–246.

5. Kochersberger G, McConnell E, Kuchibhatla MN, Pieper C. The reliability, validity, and stability of a measure of physical activity in the elderly. *Arch Phys Med Rehabil*. 1996;77:793–795.

6. US Public Health Service, US Department of Health and Human Services. *Physical Activity and Health: A Report of the Surgeon General*. Atlanta, Ga: US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, The President's Council on Physical Fitness and Sports; 1996.

7. Hahn RA, Teutsch SM, Rothenberg RB, Marks JS. Excess deaths from nine chronic diseases in the United States, 1986. *JAMA*. 1990;264:2654–2659.

8. Hicks AL, Martin KA, Ditor DS, et al. Long-term exercise training in persons with spinal cord injury: effects on strength, arm ergometry performance and psychological well-being. *Spinal Cord*. 2003;41:34–43.

9. Wettenhahn KA, Hanson C, Levy CE. Effect of participation in physical activity on body image of amputees. *Am J Phys Med Rehabil.* 2002;81:194–201.

10. Mezghani-Masmoudi M, Guermazi M, Feki H, Ennaouai A, Dammak J, Elleuch MH. The functional and professional future of lower limb amputees with prosthesis. *Ann Readapt Med Phys*. 2004;47:114–118.

11. Kegel B. Physical fitness: sports and recreation for those with lower limb amputation or impairment. *J Rehabil Res Dev Clin Suppl.* 1985;1:1–125.

12. Legro MW, Reiber GE, Czerniecki JM, Sangeorzan BJ. Recreational activities of lower-limb amputees with prostheses. *J Rehabil Res Dev.* 2001;38:319–325.

13. Chin T, Sawamura S, Fujita H, et al. Physical fitness of lower limb amputees. *Am J Phys Med Rehabil.* 2002;81:321–325.

14. Mizuno N, Aoyama T, Nakajima A, Kasahara T, Takami K. Functional evaluation by gait analysis of various ankle-foot assemblies used by below-knee amputees. *Prosthet Orthot Int.* 1992;16:174–182.

15. Stepien JM, Cavenett S, Taylor L, Crotty M. Activity levels among lower-limb amputees: self-report versus step activity monitor. *Arch Phys Med Rehabil.* 2007;88:896–900.

16. Donatelli R. *The Biomechanics of the Foot and Ankle*. Philadelphia: F. A. Davis Company; 1990: 9–27.

17. Coleman KL, Smith DG, Boone DA, Joseph AW, del Aguila MA. Step activity monitor: long-term, continuous recording of ambulatory function. *J Rehabil Res Dev.* 1999;36:8–18.

18. Bennet L, Kavner D, Lee BK, Trainor FA. Shear vs pressure as causative factors in skin blood flow occlusion. *Arch Phys Med Rehabil.* 1979;60:309–314.

19. Sanders JE, Daly CH, Burgess EM. Interface shear stresses during ambulation with a below-knee prosthetic limb. *J Rehabil Res Dev.* 1992;29:1–8.

20. Sanders JE, Lam D, Dralle AJ, Okumura R. Interface pressures and shear stresses at thirteen socket sites on two persons with transtibial amputation. *J Rehabil Res Dev.* 1997;34:19–33.

21. Dudek NL, Marks MB, Marshall SC. Skin problems in an amputee clinic. *Am J Phys Med Rehabil*. 2006;85:424–429.

22. Salawu A, Middleton C, Gilbertson A, Kodavali K, Neumann V. Stump ulcers and continued prosthetic limb use. *Prosthet Orthot Int*. 2006;30:279–285.

23. Meulenbelt HE, Geertzen JH, Dijkstra PU, Jonkman MF. Skin problems in lower limb amputees: an overview by case reports. *J Eur Acad Dermatol Venereol*. 2007;21:147–155.

24. Sanders JE, Zachariah SG, Baker AB, Greve JM, Clinton C. Effects of changes in cadence, prosthetic componentry, and time on interface pressures and shear stresses of three trans-tibial amputees. *Clin Biomech*. 2000;15:684–694.

25. Sanders JE, Zachariah SG, Jacobsen AK, Fergason JR. Changes in interface pressures and shear stresses over time on trans-tibial amputee subjects ambulating with prosthetic limbs: comparison of diurnal and six-month differences. *J Biomech.* 2005;38:1566–1573.

26. Sanders JE, Jacobsen AK, Fergason JR. Effects of fluid insert volume changes on socket pressures and shear stresses: case studies from two trans-tibial amputee subjects. *Prosthet Orthot Int*. 2006;30:257–269.

27. Sanders JE, Nicholson BS, Zachariah SG, Cassisi DV, Karchin A, Fergason JR. Testing of elastomeric liners used in limb prosthetics: classification of 15 products by mechanical performance. *J Rehabil Res Dev*. 2004;41:175–186.

28. Klute GK, Berge JS, Segal AD. Heel-region properties of prosthetic feet and shoes. *J Rehabil Res Dev.* 2004;41:535–546.

29. Gard SA, Konz RJ. The effect of a shock-absorbing pylon on the gait of persons with unilateral transtibial amputation. *J Rehabil Res Dev*. 2003;40:109–124.

30. Berge JS, Czerniecki JM, Klute GK. Efficacy of shock-absorbing versus rigid pylons for impact reduction in transtibial amputees based on laboratory, field, and outcome metrics. *J Rehabil Res Dev*. 2005;42:795–808.

31. Flick KC, Orendurff MS, Berge JS, Segal AD, Klute GK. Comparison of human turning gait with the mechanical performance of lower limb prosthetics transverse rotation adapters. *Prosthet Orthot Int.* 2005;29:73–81.

32. Hafner BJ, Sanders JE, Czerniecki J, Fergason J. Energy storage and return prostheses: does patient perception correlate with biomechanical analysis? *Clin Biomech*. 2002;17:325–344.

33. Graham LE, Datta D, Heller B, Howitt J, Pros D. A comparative study of conventional and energy-storing prosthetic feet in high-functioning transfemoral amputees. *Arch Phys Med Rehabil.* 2007;88:801–806.

34. Zmitrewicz RJ, Neptune RR, Walden JG, Rogers WE, Bosker GW. The effect of foot and ankle prosthetic components on braking and propulsive impulses during transtibial amputee gait. *Arch Phys Med Rehabil*. 2006;87:1334–1339.

35. Lehmann JF, Price R, Fergason J, Okumura R, Koon G. Effect of prosthesis resonant frequency on metabolic efficiency in transtibial amputees: a study in progress (abstract 035). *Rehabilitation R&D Progress Reports*. 1999.

36. Buckley JG. Sprint kinematics of athletes with lower limb amputations. *Arch Phys Med Rehabil*. 1999;80:501–508.

37. Soderberg B, Ryd L, Persson BM. Roentgen stereophotogrammetric analysis of motion between the bone and the socket in a transtibial amputation prosthesis: a case study. *J Prosthet Orthot*. 2003;15:95–99.

38. Burkett B, Smeathers J, Barker T. Walking and running inter-limb symmetry for paralympic trans-femoral amputees, a biomechanical analysis. *Prosthet Orthot Int.* 2003;27:36–47.

39. Burkett B, Smeathers J, Barker T. Optimising the trans-femoral prosthetic alignment for running, by lowering the knee joint. *Prosthet Orthot Int*. 2001;25:210–219.

40. Buckley M, Heath G. Design and manufacture of a high performance water-ski seating system for use by an individual with bilateral trans-femoral amputations. *Prosthet Orthot Int*. 1995;19:120–123.

41. Nair A, Heffy D, Rose D, Hanspal RS. Use of two torque absorbers in a trans-femoral prosthesis of an amputee golfer. *Prosthet Orthot Int.* 2004;28:190–191.

42. Rogers JP, Strike SC, Wallace ES. The effect of prosthetic torsional stiffness on the golf swing kinematics of a left and a right-sided trans-tibial amputee. *Prosthet Orthot Int.* 2004;28:121–131.

43. Ferrara MS, Peterson CL. Injuries to athletes with disabilities: identifying injury patterns. *Sports Med*. 2000;30:137–143.

44. Klenek C, Gebke K. Practical management: common medical problems in disabled athletes. *Clin J Sport Med*. 1999;17:55–60.

45. Ephraim PL, Wegener ST, MacKenzie EJ, Dillingham TR, Pezzin Le. Phantom pain, residual limb pain, and back pain in amputees: results of a national survey. *Arch Phys Med Rehabil*. 2006;86:1910–1919.

46. Royer T, Koenig M. Joint loading and bone mineral density in persons with unilateral, trans-tibial amputation. *Clin Biomech.* 2005;20:1119–1125.

47. Rabuffetti M, Recalcati M, Ferrarin M. Trans-femoral amputee gait: socket-pelvis constraints and compensation strategies. *Prosthet Orthot Int*. 2005;29:183–192.

48. Kulkarni J, Adams J, Thomas E, Silman A. Association between amputation, arthritis and osteopenia in British male war veterans with major limb amputations. *Clin Rehabil.* 1998;12:348–353.

49. Norvell DC, Czerniecki JM, Reiber GE, Maynard C, Pecoraro JA, Weiss NS. The prevalence of knee pain and symptomatic knee osteoarthritis among veteran traumatic amputees and nonamputees. *Arch Phys Med Rehabil*. 2005;86:487–493.