LECTURES 13-14: LOWER LIMB PROSTHETICS FOR SPORTS AND RECREATION

13.1 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. 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.

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.

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.

13.2 WHEN TO PROVIDE A SPORTS-SPECIFIC PROSTHESIS

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 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).

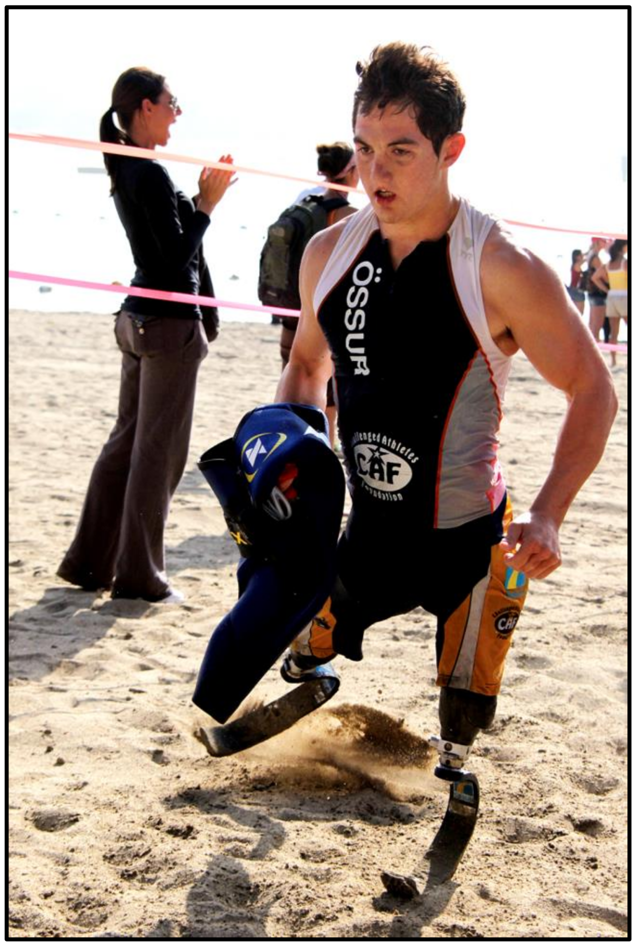

Figure 1. Exiting the water using short, nonarticulated prostheses provides stability and function during the triathlon transition.

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.

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 1).

13.3 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.

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.

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.

13.4 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.

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.

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.

The greater the shear forces generated with a prosthesis, the lower the pressure required to cause tissue breakdown. 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.

13.5 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. 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 3).

13.6 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.

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. 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.

Figure 3. Upright control while surfing is enhanced when using straight pylons on the transfemoral prosthesis.

13.7 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 4).

Prosthetic limb kinematics have been shown to mimic this able-bodied data. 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.

Figure 4. Running-specific foot modules are used to mimic natural running biomechanics.

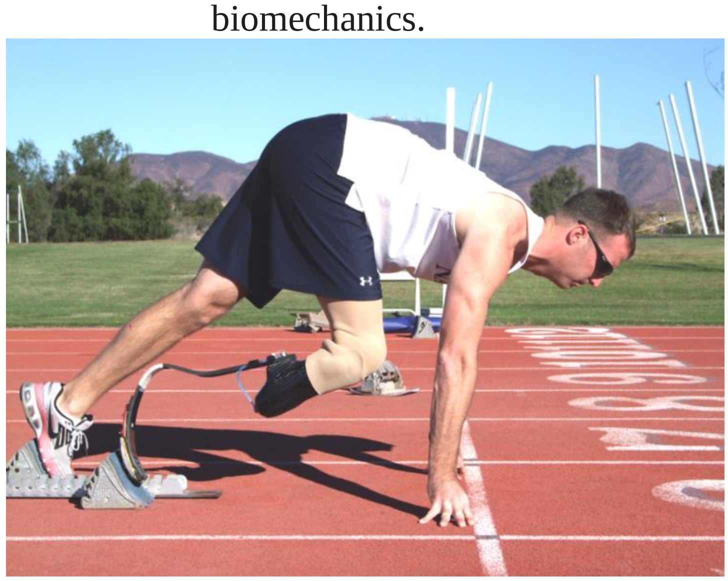

Figure 4. Running-specific foot modules are used to mimic natural running biomechanics.

If the amputee desires to sprint and short bursts of speed are the goal, a sprint-specific foot should be considered (Figure 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.

13.8 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 a viable option when stability is a concern

Figure 6. Transfemoral runners can use a non-articulating limb with a circumducted gait to increase stance stability and energy efficiency.

Figure 7. Transfemoral runner exhibiting a knee flexion running gait using a hydraulic single axis knee, sprint foot, and 20-degree angle bracket.

or when suitable cardiovascular endurance has not yet been attained. Training begins with a circumducted gait to allow foot clearance in swing.

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.

13.9 CYCLING

Cycling is an excellent exercise that is no weight 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 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.

Figure 8. Paralympic cyclist with a direct attached carbon fiber foot and shin system to enhance aerodynamic efficiency.

Figure 9. Transfemoral amputee exhibiting free swing from a seven-axis knee with a direct attached carbon foot system.

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 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.

13.10 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 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 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.

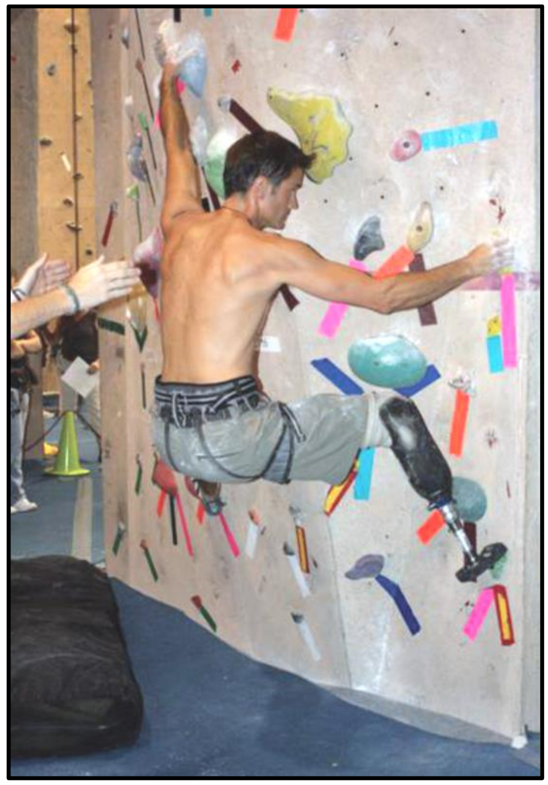

Figure 21-10. Custom foot module with spikes and Kevlar is used to increase traction while scaling an indoor rock-climbing wall.

13.11 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 11). For the bilateral transfemoral patient, prosthetic devices are usually bypassed in favor of specialty seating systems that allow participation at the highest levels.

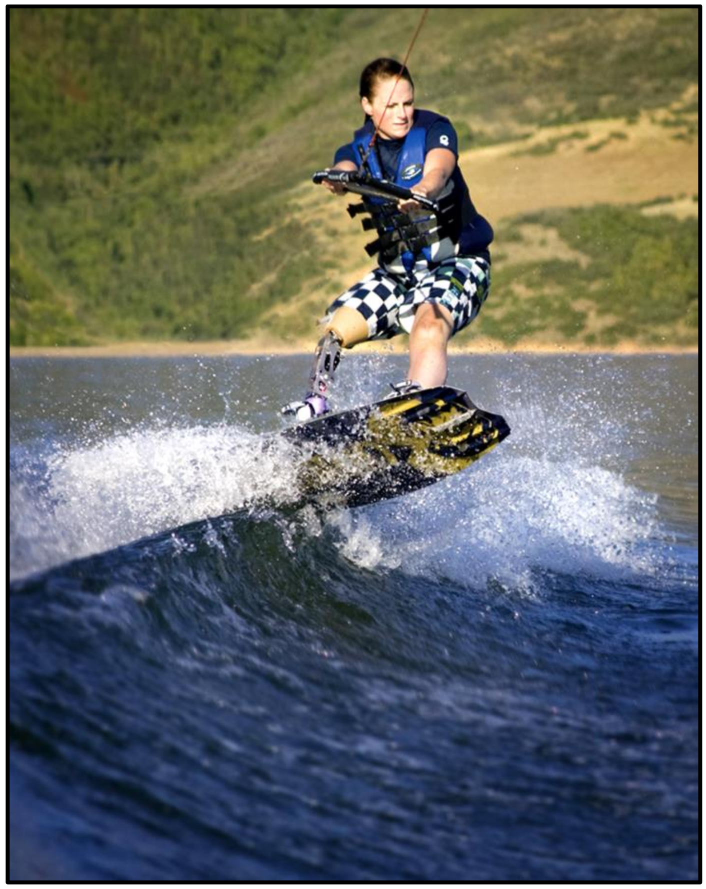

Figure 11. Wake boarding is made possible with sports-specific knees that provide stability with flexion- and extension-assisted support.

13.12 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 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.

Figure 12. Advanced dynamic sport knee builds energy during flexion and returns energy in extension to provide superior control for the transfemoral skier.

Unilateral transfemoral skiers will usually opt to use a single ski with bilateral forearm outriggers (Figure 13). The immense popularity of snowboarding has accelerated developmental designs for the transfemoral amputee.

Figure 13. Adaptive ski poles for the downhill skier replaces the need for a sports-specific prosthesis

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 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 14. No additional adaptive gear is necessary for this transfemoral snowboarder when using this energy-storing prosthetic knee.

13.13 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 Tri planar 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 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.

Figure 15. Torsion control systems allow for proper swing mechanics for the amputee golfer.

13.14 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.

13.15 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).

Spine and intact limb injuries are also common to the amputee. 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 bothersome Ness. Amputees have also been shown to suffer from various comorbidities associated with biomechanical abnormalities.