Chapter 24

UPPER LIMB PROSTHETICS FOR SPORTS AND RECREATION

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INTRODUCTION

The expansion and sophistication of technology, services, and communications in the 21st century is creating many new lifestyle opportunities for adults. Improved lives and lifestyles resulting from this expansion provide additional leisure time that can be directed at sports and recreational endeavors. Experts from the Centers for Disease Control and Prevention report that both physical and mental well-being are enhanced by physical activity.[1] In January 2007, the US government established the first federal medical classification code for upper limb prosthetic attachments for sports and recreation.[2] Sports and recreation activities have been linked to successful rehabilitation, and games and sports encourage socialization within selected micro and macro-social systems.[3] Therapeutic recreation and adaptive physical education programs help implement these avocational components into comprehensive rehabilitation programs.

There has been a growing demand for sports-specific (activity- or task-specific) prosthetic devices since the 1970s. In 1970, only a couple of simple adaptations were available for baseball and bowling. Today, a growing selection of adaptive prosthetic accessories are available that enable combat amputees to participate competitively in sports and task-specific activities. Most of today's combat veterans dealing with the challenges of a traumatic upper limb amputation are 20 to 30 years old and have the same dreams, drives, and needs as others their age. Through comprehensive rehabilitation, these amputees can participate in the same sports and recreational activities they enjoyed before they were injured. As survival rates continue to rise for traumatically injured service members, so will the demand for activity-specific prostheses. Knowledge of prosthetic sports and recreation equipment that is currently being developed in active military medical centers will eventually be incorporated into the care at national Veterans Administration hospitals, ensuring that combat amputees will continue to pursue specialized high-performance activities into the future.

ADVANCES IN PROSTHETIC TECHNOLOGY

The last 25 years have given rise to significant improvements in prosthetics materials and designs. Aerospace materials, such as carbon fiber and titanium, are now commonly incorporated into high-performance prosthetic limbs. High-strength resins and innovative suspension designs (with more intimate anatomical interfaces), combined with high-efficiency, body-powered systems or electromechanical components, provide better control, energy transfer, and delivery of biomechanical forces through prostheses. Roll-on silicone liners can augment suspension for better control throughout greater ranges of motion. Silicone liners excel in aqueous environments, where water lubricity makes it difficult to secure adequate suspension; however, they are not appropriate for all patients or environments. Myoelectric and electromechanical arms are not used in sports and recreation activities as often as traditional body-powered prostheses, probably because of the myolimb's inherent construction and more fragile, environmentally sensitive components. An externally powered arm is best used for activities and in environments that ensure its prolonged function and lifespan. The high impact and environmental exposure that result from many sports and recreational activities dictate that only a very durable, reliable, and functional prosthesis be constructed and used for these purposes.

Improved self-suspending socket designs[4] and a variety of new thermoplastics and thermoplastic elastomers are available to build uncompromising, strong, and comfortable prostheses. These improved suspension systems and strong, lightweight materials allow for the use of terminal devices, or "end effectors" (ie, accessories specifically designed to accomplish particular activities). The approach that appears to be the most successful focuses on activity-specific prosthetic attachments that are designed to emulate the biomechanics of the human hand and arm in that particular activity. This has led to the development of products that allow many amputees to perform not only recreationally but competitively with their two-handed peers. The pursuit of rigorous sports activities may further advance prosthetic science, bringing about new conditions or requirements that drive prosthetic revision and innovation.

THE BALANCE BETWEEN PHYSICAL, PSYCHOLOGICAL, AND PROSTHETIC REHABILIATION

Today's combat amputee may be faced with multiple amputation injuries compounded by tissue damage from explosions and burns. Patient assessment is comprehensive and includes efforts to evaluate future sports and recreation demands. The rehabilitation process can be significantly improved when amputee patients realize that sports and recreational pursuits are real possibilities for their futures.

It is important for the rehabilitation team serving the combat amputee in both the inpatient and outpatient settings to provide the most comprehensive rehabilitation program possible. Physical, psychological, and prosthetic rehabilitation must be balanced in order to foster success. Amputees cannot expect high performance from a prosthesis if they do not exhibit adequate range of motion, muscle hypertrophy, and strength. Conversely, they cannot be expected to perform at a high level if the prosthetic technology they receive does not complement their physical capabilities. Additional therapeutic intervention may be useful at this point in rehabilitation. The rehabilitation team should always endeavor to instill a positive attitude in the amputee and set realistic goals for accomplishing higher performance tasks. The combat amputee needs to be aware of the rehabilitation balance to focus perspective and direct rehabilitation. A direct involvement in rehabilitation decision making helps patients visualize the goals that need to be achieved. Specialty prostheses are prescribed and applied later in the rehabilitation cycle, following preliminary training and successful use of myoelectric and basic body-powered prostheses. Sports and recreation challenges are incorporated into the combat amputee's rehabilitation goals as soon as is realistically possible.

PREPROSTHETIC EXERCISE

Preprosthetic exercise should be considered in all cases where a definitive prosthesis cannot be applied or tolerated because of the severity of the injuries, tissue damage, skin grafts, or the like. In these cases, a padded, weighted harness may provide the patient with the ability to stimulate the muscles of the arm and shoulder, improving strength and range of motion. On a weighted harness with a transradial design, a triceps cuff is attached with flexible hinges to a padded cuff. The padded cuff is equipped with D-rings and a strap onto which disc weights can be added. The triceps cuff should strap above and below the biceps to prevent the harness from slipping off without inhibiting flexion. The padded cuff helps reduce abrasion to the tissues of the forearm while it supports the weights. The cuff should be placed as distally as possible to maximize resistance, but should not slide off the end of the arm. A weighted harness with a transhumeral design should replicate a standard figure-eight harness, padded as necessary to help reduce abrasion. Instead of terminating into a triceps cuff on the affected arm, a padded cuff, similar to that described for the transradial vest, can be applied. Weights can be added, and the therapist can create a variety of exercises to stimulate the musculature of the shoulder and remnant upper limb. A padded, weighted harness is an alternative to elastic-band or rubber-tube resistance exercise systems and can offer physiological benefits that those systems cannot provide.

BIOMECHANICS AND HUMAN MOVEMENT

In the past decade, there have been significant improvements in the design and function of activity-specific prosthetic devices. A focus on human movement and biomechanics has led to the development of prosthetic devices that integrate with the human body's biomechanics, allowing for improved movement and energy transfer through the torso and into the prosthesis. This is important for activities that require the dynamic (gross motor) use of the upper body, such as golfing and baseball. Improved range of motion throughout the forearm and at the wrist allow for two-handed function, more accurate control, and higher performance with a prosthesis than before.

Altering the design focus away from "one-model-fits-all" to activity specific has allowed for an evolution of products that may only excel in particular tasks and environments. Because of their specificity in function, these products harmonize with the physical demands of a particular activity, providing amputees with improved potential for performance and success. These new "focused" designs can help combat amputees meet the challenges of being actively involved and competitive in sports and recreation in a two-handed world.

PROSTHETIC DESIGN FOR SPORTS AND RECREATION

Understanding the biomechanics involved in performing a particular sport is the first step in providing a prosthetic solution. Certain activities, such as basketball, volleyball, and soccer, rely on bilateral hand function (volar hand surface control) that essentially ignores traditional opposed thumb (three chuck pinch) prehension. Other activities, such as baseball and golf, are successfully accomplished only when there are multiple degrees of freedom in the torso and arms and when efficient energy transfer is possible. The hand prehension aspects that may be required for a sport are not as important for performance; thus, analyzing and understanding an activity's demands is the primary concern, followed by an effort to duplicate those characteristics in a prosthesis. In certain circumstances, it is not feasible to easily duplicate what is required and innovative solutions are developed.

Another important element that must be considered is safety. Sheathing the hard exterior shell of a prosthesis with a stretchable, soft, padded cover helps protect the user and other players from injury. A 5-mm thick neoprene wetsuit material (fabric both sides or a variant) can be made into a sports cover that looks good and provides a safety cushion from impact. A variety of new sports-specific prosthetic accessories are designed to minimize or eliminate the potential for injury.

Archery and Weight Training

It may appear odd to group these two radically different activities together, but they have prosthetic design commonalities. Most prostheses are designed with a preflexion angle between the socket's center line and the forearm center line, so the face can be reached with a terminal device, prehensor, or hand. This type of preflexion alignment is counterproductive to many sports activities because it inhibits full arm extension when compared to an anatomical limb.

In archery and weight training, proper prosthetic alignment is critical to performance. A neutral alignment that allows for even loading of distally applied forces is necessary for control and performance. An improperly aligned prosthesis under load would be difficult to control, especially for the amputee with a short- to medium-length forearm (much like balancing a heavy weight on the end of a long stick). A preflexed socket inhibits performance in these activities because the alignment creates forces in and on the prosthesis that cannot be easily controlled.

In archery, the successful drawing of the arrow and its accurate release and true flight are impacted by prosthetic alignment (Figures 24-1 and 24-2). An improperly aligned prosthesis makes it impossible to accurately draw and release an arrow, especially when dealing with bows that have a draw weight in excess of 45 lb. Custom attachments have been developed to connect to a bow or attach to the bow string. Voluntary closing terminal devices with a prehensile configuration conform to most bow risers when a soft cushion is wrapped around the handle. The cushion allows the handle and bow to center in the device's grasp, helping eliminate torque when the arrow is released. Simple locking systems allow the bow to be held without concentration on cable tension (Figure 24-3). Another prosthetic accessory is designed to allow an archer to clip on to the bowstring and release it mechanically with a lever that can be triggered by a chin nudge or other movement (Figure 24-4). Shooting a bow involves eye and hand dominance, so in many cases it is best to develop a solution that conforms to existing eye dominance traits.

Some other techniques and devices make archery accessible to those with hemiplegia or high-level limb absence. Mouth tabs and chest-suspended or chest-supported triggering systems help single-handed archers effectively and accurately shoot a bow and arrow.

The proper alignment of a prosthesis may dictate a user's ability to safely control weights while performing some weight-lifting exercises, such as bench press or dumbbell flies (Figures 24-5 and 24-6). Without a properly aligned and securely suspended prosthesis, an amputee with a medium or short residual limb will struggle to balance and control a barbell or dumbbell throughout the exercise's range of motion. A prosthesis built with a neutral (not preflexed) alignment is best for weight lifting. Carbon fiber can be added into the socket and forearm for strength. A self-suspending design may prove useful when combined with a roll-on liner and integral locking system for added suspension. If a thin roll-on liner is used, an additional partial liner of foam fabricated into the prosthesis will provide protection for the olecranon and elbow condyles (Figure 24-7). Such padding helps mitigate the pressure points created when the prosthesis sustains torque from a heavy load. Harnessing should be kept at a minimum because it typically restricts range of motion. Depending on the activity and the design of the prosthesis, a harness may not be necessary.

Conventional voluntary opening, split-hook technology, commonly used in prosthetics for simple ADLs, has proven ineffective for these types of high-performance activities. The prehension requirements of the activities, especially weight lifting, supersede the capabilities of almost all split-hook designs. Certain voluntary closing prehensors are designed and constructed to perform in both archery and weight lifting. The prehensile configuration includes opposed thumb grasp, which conforms to cylindrical shapes and handles, improving stability and control. These devices operate best when they are modified with a simple accessory locking system that eliminates the need to maintain cable tension in the body-powered harness for grasping and holding (Figures 24-8 and 24-9).

One system designed specifically for weight training is intended for light or moderate weight exercise (Figure 24-10). Another system includes two models. One is capable of withstanding extreme loads, including those used in Olympic events. The second model is more compact, lighter, and is designed for general gym weight training and conditioning (Figures 24-11 and 24-12). Both provide solid, stable control of barbells, dumbbells, and other weight-training equipment.

Golf and Baseball

Golf club and bat swinging require prostheses that provide appropriate degrees of freedom and control to allow for the efficient transfer of energy from the torso and body through the arms and prosthesis into the club or bat. Traditional or conventional prosthetic wrist components and terminal devices do not provide these capabilities.

Additionally, the site of the hand absence (right or left) and hand and swinging dominance dictate different solutions. There are a variety of prosthetic golf accessories; in the 1980s, most were custom made, single-use designs (devices built for use by a single individual and not intended for mass manufacturing). Experimentation was conducted to design a device that could duplicate the biomechanics in the wrist and forearm and produce a smooth swing and energy transfer. A flexible power coupling has evolved to be the best solution that fits the needs of most golfers. The length and stiffness of the coupling varies based on hand absence, swing-side dominance, and level of amputation. One golf device is designed primarily for right-handed individuals with left hand absence (Figure 24-13). The device can also be used by right-hand amputees who golf left handed, but a crossover grip is required. Although a second hand with normal gripping capability is required to use it, the device is versatile and can be easily adjusted to fit onto any golf club, adapting to the grip's diameter and taper.

Another alternative prosthetic golf system has models for both right and left hands to accommodate the differences (Figures 24-14 and 24-15). It uses a flexible coupling design similar to the device previously described, but the coupling stiffness is variable and the club attachment designs are different, dictating that uniform club grips be used. These devices are suitable for golfers with compromised strength, dexterity, or prehension in their second hand; they require only minimal assistance from another hand for club engagement. The application for bilateral amputees is viable. Typically, it is best to apply this device to the natural leading arm and allow the amputee golfer to experience and develop a controlled, one-handed swing using the prosthesis or residual arm for guidance and stability. Unique and individual solutions evolve for the second prosthesis, if required, as experience grows.

It is also possible, with the help of custom golf clubs modified with adapters, to directly and rigidly attach a golf club to a prosthesis. Although it is less convenient, this alternative may solve some control problems for amputee golfers.

Golf prostheses for individuals with transhumeral absence have evolved significantly since the 1990s. High-performance designs now use short sports prostheses that terminate in a wrist component, which is mounted anatomically close to where the normal elbow exists. A custom, lightweight, energy-storing, power-coupling device can entirely eliminate the need for a traditional prosthetic elbow or forearm.These couplings are designed to terminate into one of the previously described attachments. Prosthetic suspension can take advantage of roll-on locking liners to ensure unrestricted range of motion or use more traditional harnessing. Lightweight, carbon-reinforced prosthetic sockets help ensure that these short sports prostheses can tolerate the loads involved in the activity.

Swinging a bat has many of the same biomechanical challenges as swinging a golf club. In the past, many amputees batted single-handed, but being able to swing a bat two-handed using a prosthesis can improve performance. An innovative device for bat swinging is molded entirely from a strong, energy-storing, flexible polymer and is designed to quickly pry on and off the bat handle for convenience and safety (Figure 24-16). It uses a threaded mounting stud to fit any standard screw in a friction or disconnect wrist, and is designed to be grasped with an overhand grip from the sound hand. The device is versatile enough to allow function for either right or left hand absence and right or left hand swing preference.

Catching a ball adds additional challenges and choices for the amputee. Some prefer to play single handedly, transferring the glove on and off the sound hand as required. Others prefer to function with a prosthesis. Catching a ball below the waist requires that the forearm and glove are supine; catching above the waist requires pronation. For mid- or short-transradial amputees, these movements are impossible; merely placing a baseball glove on a prosthesis does not account for all the dynamic action involved. One prosthetic device made for baseball is designed to fit into a first-baseman's glove (Figure 24-17). The device is cable operated and functions like a large, voluntary opening split hook that is pulled and held open, then released to catch. Manual pronation and supination are required using the sound hand.

Another design replaces the traditional glove with a large mesh pocket so a ball can be caught forehanded or backhanded, eliminating the need to pronate or supinate the forearm (Figure 24-18). This lightweight, high-performance alternative meets the surface area requirements for gloves in regulated play.

Canoeing and Kayaking

Canoeing and kayaking require full range of motion and upper body coordination and strength. Manipulating handles and shafts requires different hand grasping configurations. Canoeing typically involves alternating paddling from starboard to port, complicating the situation for the amputee canoeist using a prosthesis because of the different grasps required.

A prosthetic finger or thumb can be inserted into a large-diameter hole drilled through a canoe handle. The improved articulation created with this modification is usually sufficient to allow the paddle to be controlled through a wide range of motion. The shaft is usually easy to grasp with a voluntary closing prehensor. Voluntary opening split hooks do not perform well because of their configuration and limited prehension, and have a tendency to pry off paddles under load. Padding or wrapping the shaft can improve control with most devices. Myoelectric prostheses can be useful for general recreational paddling; however, accidental immersion is a factor and must be considered. These factors usually preclude the use of myoelectric prostheses in river and whitewater boating.

A new kayak and water sports prosthetic accessory attempts to meet the performance demands of river and whitewater kayaking, but also functions in flat water environments (Figure 24-19). It employs a quick connect and disconnect power strap to secure the kayak paddle shaft or canoe oar. The power strap stores energy as it is stretched from side to side, duplicating a radial–ulnar type of wrist articulation. A standard prosthetic wrist provides the additional adjustable, rotational friction needed for smooth paddling. The energy storage and return action allow for comfortable, forceful propulsion with a double-ended kayak or canoe paddle.

Basketball, Volleyball, and Soccer

Duplicating the volar (palmar) surface of the hand is important for activities that require coordinated bimanual function. A flexible interface that conforms to the large spherical surfaces of soccer balls, volleyballs, and basketballs also enhances control, improves performance, and provides some protection and safety. Several prosthetic accessories were specifically designed to emulate these hand characteristics and provide function and performance in these activities (Figures 24-20, 24-21, and 24-22). They are constructed of strong and flexible polymers that store and return energy, which helps duplicate certain wrist-like functions for improved ball handling and control.

Swimming

Swimming also requires the use of the volar hand surfaces, but for propulsion rather than manipulation. Prosthetic paddles or fins can enhance resistance during the power phase of a swimming stroke, improving propulsion but possibly impeding efficiency because often the amputee cannot pronate or "feather" the paddle or fin while swimming. This drag can be eliminated with a flexible or folding fin system. One swimming accessory with a folding fin is designed to be used on a custom, lightweight, short sports prosthesis specifically built for the water environment (Figure 24-23). Polypropylene, polyethylene, or copolymer materials are appropriate for use in the socket. A roll-on locking liner counteracts the water's natural lubricity, improving suspension for better control and higher loads during the power stroke. The fin collapses during retrieval, reducing or eliminating the water drag that a flat, rigid fin would create.

Amputees can swim without a prosthesis, but a prosthesis provides better propulsion and performance. The added resistance of a swimming fin or paddle is also therapeutic to the muscles of the upper arm, shoulder girdle, and upper torso, creating stimulation for growth and hypertrophy.

A prosthetist can use a kit to fabricate a flexible swimming paddle that is designed to fit directly onto a residual limb (Figure 24-24). This device can be a good introductory aid for therapeutic physical exercise before an amputee is fit with a prosthesis, or for amputees who cannot tolerate a normal prosthetic limb.

Steering, Vehicle Control, and Other Activities with Similar Upper Extremity Demands

Bimanual capability and rapid and reflexive grip and release are functions that enable safe and effective vehicle control, whether the vehicle is body powered or motor driven. Road and mountain bicycles, motorcycles, all terrain vehicles, watercraft, and automobiles emphasize the need for coordinated bimanual function. High grasping forces may be required for control in certain circumstances. Quick release may also be required to avoid or mitigate injury. Manipulating handlebars, steering wheels and other steering controls, shifts, and levers requires accurate, variable prehension from a prosthesis and is enhanced by the natural, directly proportional feedback generated by active or positive-grasping, voluntary closing prosthetic prehensors. Devices equipped with polymer gripping surfaces provide better control in these types of activities than devices with smooth metal or serrated surfaces. Driving and steering usually involve glenohumeral flexion, and voluntary closing devices harmonize with that biomechanical motion (Figures 24-25 and 24-26). Myoelectric hands and control systems also perform well and are reliable for activities that involve driving and steering, although direct positive feedback is not available with this technology.

Split hooks are actuated and controlled by a body harness in such a way that gripping control and stability can be compromised while driving or riding. Additionally, the split-hook configuration does not lend itself to handling the cylindrical shapes and curved or rounded surfaces that are often encountered with these activities. Split hooks produce a gripping feedback that is inversely proportional and therefore counterproductive to progressive gripping control.

Handlebars can be padded or cushioned to improve their frictional coefficients for better handling. Controls can be clustered together for easier, safer one-handed operation. Motorcycle controls can be grouped and integrated. The motorcycle twist throttle grip is easily combined with a lever action clutch and can be controlled simultaneously with the sound hand while the prosthesis is used primarily for handlebar control. Front and rear hydraulic brake systems can be integrated together to be operated independently with a single foot pedal or lever.

Similarly, front and rear mountain bike brake cables can be integrated to operate off a single lever, freeing the prosthesis to be used for handlebar stability and control (Figure 24-27). The progressive and powerful gripping capabilities of the voluntary closing prehensor easily withstand the bouncing and jarring conditions typical in off-road terrain. Should a fall occur, relaxation of cable tension in the system automatically releases the voluntary closing device from the handlebars, freeing the rider from the bike. Myoelectric prostheses also have the gripping capacity and control to meet these riding challenges. Rough off-road use creates significant shock and vibration that can be harmful to the function of electromechanical prostheses.

Two models of recreational-grade prosthetic bicycle accessories are available to suit different ages, abilities, and riding styles (Figure 24-28). These devices are constructed of flexible polymers and operate like rubber cleats, snapping on and off the handlebars. They are safe, lightweight, and easy to use.

Fishing

Handling fishing reels and rods for sport fishing requires bimanual function and coordination. It is important to manipulate handles and gears with a terminal device that provides controlled and adequate grasp. A simple, functional approach is to hold and control the fishing rod when possible with the sound hand and reel with the prosthesis (Figure 24-29). Accurately controlling a fishing rod in an activity like casting requires wrist action that prosthetic wrists do not provide.

One alternative prosthetic accessory consists of a rod system directly attached into the prosthesis (Figure 24-30). Another adapter is used to cradle and stabilize the rod in the prosthesis, but is not practical for casting (Figure 24-31). These systems are appropriate for anglers who prefer to use a prosthesis for rod handling or who cannot control a fishing rod with a sound hand and limb.

Most fishing reels can be easily modified to be more functional with a prosthetic terminal device. Slip-on rubber grips can stretch over most reel handles, making them easier to grasp with a prosthetic device (Figure 24-32). Myoelectric hands and externally powered hooks, as well as voluntary closing prehensors, can be used for reeling. Split hooks do not typically provide enough grasping force to be effective and tend to pry off the fishing reel handle under load. Most standard bait-casting and spinning reels, either open or closed face, can be easily manipulated. Reeling-specific prosthetic devices are also available (Figure 24-33). However, these products leave the angler single-handed for performing the other activities that are required while fishing (ie, changing lures, flies, and bait; netting fish; handling boating equipment; etc).

Fly-fishing requires coordination, bimanual dexterity, and gross motor upper limb involvement. The prosthesis should be capable of handling the fly line or the fly rod. Controlling the rod with the prosthesis is difficult in most cases because of the lack of freedom in most prosthetic wrists. Fly-fishing requires that the line be cast (instead of just the lure or fly). The fly line can be handled accurately with a prosthesis that provides controlled gripping force and some type of sensory feedback (eg, a voluntary closing prehensor with polymer gripping surfaces provides traction to control the line without damaging it; Figure 24-34). Fly-fishing is different than other types of fishing in that the line is not usually retrieved by reeling, but is pulled in by hand when a fish is caught and reeled up after the fish is netted. An individual who has experience with a voluntary closing prosthesis can potentially develop the technique, dexterity, and control to fly-fish. A few general accessories that help with holding small flies, dealing with fine leaders, and tying knots are also useful tools for creating a positive, successful fly fishing experience. Advances in myoelectric technology may make it possible to fly-fish with an electric hook prosthesis. The myoelectric hand will not have the dexterity to control the fly line, but the electric hook with narrow, rubber-lined, hook fingers can meet these challenges. Water immersion is a risk to consider when using a myoelectric limb for fly-fishing.

Firearms

Firearms expertise is an integral part of any military experience and rehabilitation program. Service members and veterans with an amputation may find it rewarding to return to shooting as a pastime or for sport. Firearms Training Simulation facilities have been created to help amputee soldiers regain and retune their firearms skills during rehabilitation and prepare for live-fire experiences. Firearms Training Simulation facilities feature laser-fired weapons and simulated combat scenarios.

Safely handling and controlling a firearm with a prosthesis is the primary concern when engaging in shooting activities. Most pistols can be modified and retrofit with oversized, compliant grips that improve control (Figure 24-35). If myoelectric prostheses are used, the shock and stress that result from firing guns with high recoil must be considered. Some voluntary closing prehensors and myoelectric hands have an opposed thumb design that conforms to the shape of a pistol handle and can generate the level of gripping force required to safely control the firearm. An overhand grip is typically used with the sound hand to help aim and trigger the pistol.

Long guns, such as rifles, carbines, and shotguns, can be safely controlled with prostheses. The shooter must decide whether or not to modify the firearm. A variety of pistol grip attachments can be added to the fore end of a gun to allow for improved control (Figures 24-36, 24-37, and 24-38). Prosthetists should rely on trained, certified gunsmiths for modifications instead of doing them themselves. In certain cases, a simple military strap added to the gun provides enough flexibility to shoot with a prosthesis. A stainless steel or brass ring can also be added to a gun's fore end and attached into a modified post used for a normal gun sling. The ring can be grasped by a prosthetic finger or thumb.

Another alternative avoids modifying the firearm altogether (Figures 24-39, 24-40, and 24-41). This device, designed initially to safely handle an M-16 firearm, is versatile enough to shoot almost any rifle, carbine, or shotgun, including pump-action and side-by-side double barrel guns. A flexible, strong, polymer yoke contains tapered rubber fins that allow the fore end of the gun to be snapped down into place. Pulling the firearm back towards the shoulder tightens the gripping action of the yoke so that the firearm can be locked onto the shoulder for stability and control. The device has a friction-lockable, stainless steel ball and socket, and a friction-adjustable swiveling mechanism allows for a broad range of motion. The barrel can be carried up or down, and the firearm can easily be swung to the shoulder for tracking, aiming, and firing. The device's yoke firmly grasps the gun's fore end but will not mar even finely checkered walnut stocks. The gun can be loaded and reloaded while secured in the prosthesis's hold. However, this type of a device is only useful for handling firearms, leaving shooters single-handed for other activities.

Another option is a plastic-covered steel yoke, into which the fore end of a gunstock can be positioned for support (Figure 24-42). This device offers another simple alternative to the amputee shooter, but provides less total control over the firearm.

Depending on eye dominance, the shooter may wish to fire a gun with the prosthesis. This takes a lot of practice to be safe and proficient. The lack of tactile finger sensation and fine dexterous movement in prostheses make triggering a firearm with a prosthetic finger problematic. Additionally, when a human hand triggers a gun, it also operates safety mechanisms and provides support for the stock, functions that are difficult to perform with a prosthesis while triggering.

Hockey

Ice and street hockey require bimanual upper extremity involvement and coordination. A jointed or flexible coupling at the end of the prosthesis connected to a hockey stick is important for safety. A 4-ft long hockey stick will create forces of leverage that can be transferred back into the prosthesis and injure the player's residual limb if some type of flexible linkage is not used.

Handedness and playing style (right or left) can dictate whether an amputee wishes to control the stick with the prosthesis at the top or down on the shaft (trial and error may help determine the best solution). A variety of custom prosthetic attachments attempt to make handling a hockey stick easy and efficient; some try to meet the needs of either stick-handling situation (Figure 24-43). The flexible coupling on these attachments bends enough to help eliminate injury when a player is forced into the rink's walls or falls. The coupling is stiff enough to allow handling the puck with just the prosthesis when necessary.

Water-Skiing

Water-skiing, especially slalom skiing, single-handed without a prosthesis is possible but tiring and physically demanding on the muscles of the remaining arm. Custom quick-detach mechanisms can be incorporated into a water-ski rope, but they must be controlled by the skier. A custom plastic water-ski hook used in conjunction with a floating, self-suspending prosthesis can be helpful. The hook creates enough grip to engage the rope handle so the skier can ski even single-handedly with a prosthesis. If the hook fails to twist off the handle during a fall, the skier can twist out of the prosthesis, avoiding injury.

A simpler alternative is to modify the ski rope handle. A small cup or tube (sized to slide over one end of a ski rope handle) and flexible line can be attached to the prosthesis or directly to a body harness. The attachment provides leverage so the arm and prosthesis can be used to resist the pulling load of launching and control the ski rope handle. When the sound hand releases the handle, the tube pops off the other end and releases the skier. Another way to use this technique is to attach a strip of polypropylene webbing (1.5–2 in. wide) securely to the end of the prosthesis, removing the standard terminal attachment. Six to eight inches of webbing should be left loose off the end of the prosthesis and can be wrapped once or twice around the rope handle and over-grasped with the sound hand. During a fall or to release the rope, the sound hand drops the handle and the web strap pulls free, releasing the prosthesis from the tow-rope handle.

Snow Skiing and Snowboarding

Snow skiers usually rely on ski poles, while snowboarders depend primarily on their upper limbs for balance. The snowboarder or rider can use almost any type of prosthesis that provides this function and is safe to wear, considering the rider might unexpectedly fall onto the prosthesis. A prosthesis often pulls heat from the residual limb, decreasing circulation and leaving the limb colder than the rest of the body. Wearing a thin, moisture-transferring liner sock under a wool-blend sock helps keep the residual arm dry and at a more consistent temperature.

One commercially available snow skiing tool is a skiing and fishing terminal device that operates without a cable (Figure 24-44). It is fabricated from flexible silicone polymers and accepts a pole that has been stripped of the standard grip. The ski pole is forced into the device and held in place by friction. The skier thrusts the pole forward using glenohumeral flexion (arm extension), and the pole rotates forward with a pendulum action. The natural elastomeric action of the device returns the pole to its original position.

Another device can be either cable driven or used like a simple pendulum, depending on the user's preference (Figures 24-45 and 24-46). The ski pole's grip is removed and the bare tube fits into a cylindrical receiver attached to a shock-absorbing mounting system. An elastic retraction system keeps the pole flexed back out of the way until it is needed. The pole is easily removed. Natural glenohumeral flexion is used to pull on the cable, rotating the pole forward for a pole plant. A shock-absorbing module is built in to absorb the torque and stress created by using a ski pole. The device transfers upper limb power into the pole and provides the propulsion needed for Nordic skiing, yet is responsive enough to be used in moguls and for downhill pursuits.

Windsurfing

Windsurfing is a demanding activity for amputees. Windsurfers must be capable of quickly grasping and releasing the boom, sail, and control ropes. The grip required to engage and hold on is significant, and spontaneous release is important to avoid injury. A modified voluntary closing prehensor provides sufficient gripping force to control the mast and boom, and streamlined inner gripping surfaces allow for the prosthesis to be released smoothly or twisted off the boom when necessary during sailing.

The prosthesis needs to be waterproof and constructed with corrosion- and salt-resistant hardware. Leather will not survive long when repeatedly exposed to water. Roll-on silicone or similar liners, if used, should employ only strong plastic or stainless locking components. Cables have a tendency to foul with repeated exposure to saltwater; rinsing and flushing the cable system is important for efficient, reliable function. Synthetic cables constructed of polyethylene with an ultra-high molecular weight may be useful because they are strong, flexible, and naturally lubricious.

Scuba Diving

A prosthesis is not required for scuba diving and most amputee divers can become skilled enough to pass mandatory diver's certification courses single-handed. However, a prosthesis can be useful when handling gear and equipment underwater, and significantly aids climbing out of the water via a ladder. A scuba prosthesis should be designed to operate in both freshwater and saltwater environments. A voluntary opening split hook equipped with enough elastic bands will operate under a tight wetsuit, providing grasping function. The hook shape helps the diver climb ladders, get back onto the boat, and handle equipment and gear. Shorter, specially designed, lightweight prostheses that are passive and not cable operated may also be considered. A simple, strong, plastic terminal device can be designed to assist with basic functions, including ladder climbing and manipulating weight-belt buckles and other gear.

Mountaineering and Technical Climbing

Mountaineering and technical climbing require participants to be in top physical condition, possessing both strength and endurance. Good upper limb coordination, range of motion, and positive gripping force are necessary to handle equipment and meet the rigors of these activities. A stainless steel, voluntary closing device with an opposed thumb design can be used for mountaineering and climbing activities (Figure 24-47). Custom modified split hooks have also been used (Figure 24-48). Two custom climbing and mountaineering devices were designed and built with the input of amputee climbers and several other experienced able-bodied climbers (Figures 24-49 and 24-50). These designs use standardized, chromium molybdenum ("chrom-moly") climbing aids integrated into custom pedestals designed to fit onto a prosthesis. They are specific to an individual climber's requirements and capabilities, and therefore have not been made commercially available. These devices represent an example of what an amputee climber might consider using to succeed in this challenging sport.

SUMMARY

Research in upper limb prosthetics is advancing as a result of funding from the federal government. The majority of this research is oriented toward high-tech, mostly externally powered, solutions to sophisticated problems and objectives. These solutions and technology have not historically been successfully applied to sports and recreation. Performance in sports and recreation for those with upper limb prostheses has improved with sports-specific mechanical designs and innovative materials. Future developments in upper limb prosthetics for sports will most likely continue to arise from engineered, mechanical solutions that focus on duplicating the sometimes complex biomechanics involved in the performance of a specific activity. Applying energy-storing elastomers and other lightweight yet strong materials into sports-specific prostheses will improve performance. Focusing designs on the specific limitations created by various levels of amputation will also improve the capabilities and performance for a broader range of consumers. Future research and product development will be enhanced and accelerated by new financial input and resources that can be directed into this specific area of prosthetics. These resources, complemented by the innovative thinking, input, and demands of a new, young population of prosthetic users, will drive ideas and improve technology for even better performance in sports and recreation activities.

Figure 24-1. Incorrect prosthetic alignment. An improperly aligned prosthesis makes it impossible to accurately draw and release an arrow.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-2. Correct prosthetic alignment, allowing for accurate arrow draw and release**.**
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-3. TRS GRIP 2S Prehensor with locking pin holding recurve bow and arrow.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-4. Quick Release Gripper archery trigger with N-Abler (Texas Assistive Devices LLC, Brazoria, Tex).
Photograph: Courtesy of Texas Assistive Devices LLC, Brazoria, Tex.

Figure 24-5. Bench press with dumbbells using a weight-lifting prosthesis.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-6. Biceps curls with dumbbells using a weight-lifting prosthesis.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

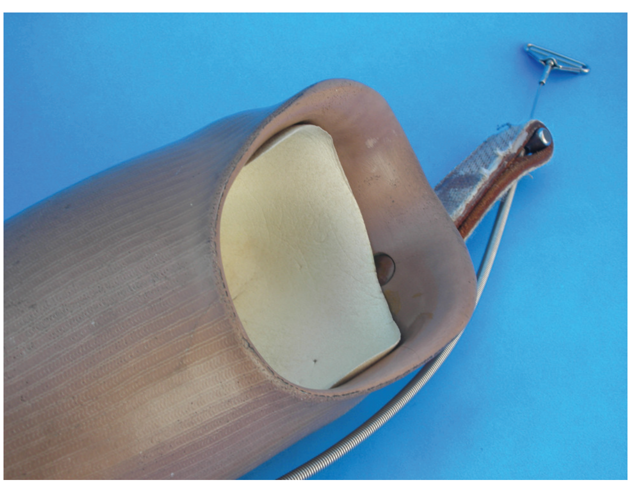

Figure 24-7. Weight-lifting prosthesis with partial liner padding.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-8. Prehensor with locking pin being used on weight equipment handle.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-9. Prehensor with locking pin modification for weight lifting.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-10. Weight-lifting device.
Photograph: Courtesy of Texas Assistive Devices LLC, Brazoria, Tex.

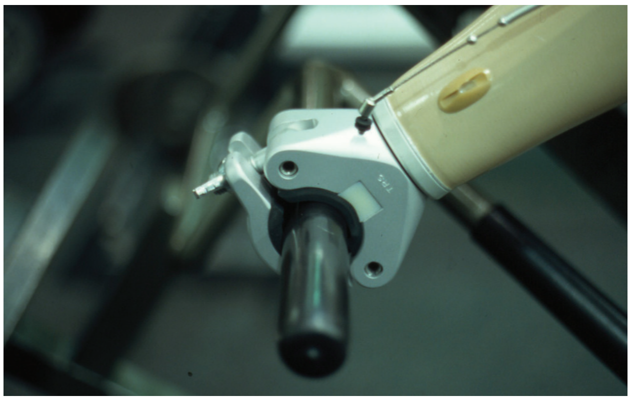

Figure 24-11. Heavy-duty weight-lifting device.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-12. Weight-lifting devices.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-13. Golf prosthesis.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-14. Golf prosthesis, left model.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-15. Golf prosthesis, right model.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-16. Baseball bat prosthesis.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-17. Baseball glove adapter split hook.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-18. Baseball catching prosthesis.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

a

b

c

Figure 24-19. Kayak accessory. **(a)** Closed. **(b)** Open. **(c)** In use. Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-20. Basketball accessory.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-21. Volleyball handling device.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-22. Soccer ball handling device.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

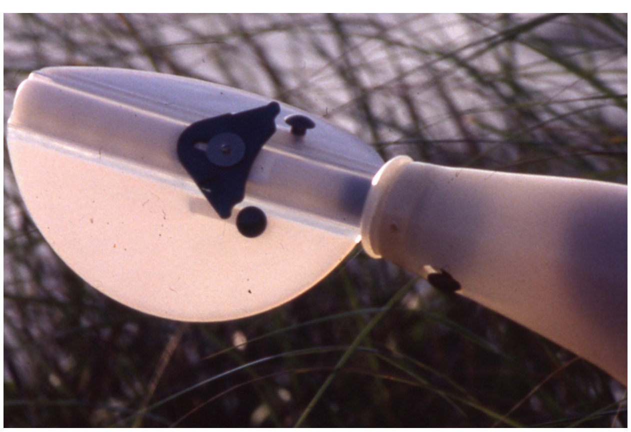

Figure 24-23. Freestyle swimming prosthesis.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

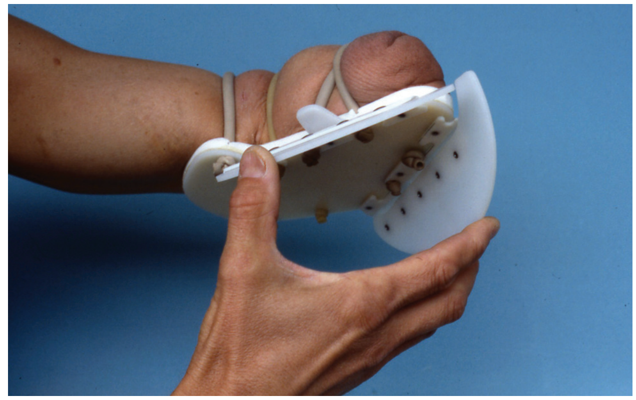

Figure 24-24. Swim fin kit (assembled).
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-25. Prehensor used with a steering wheel.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-26. Prehensor used with stick shift.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-27. Dual bike brake lever.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

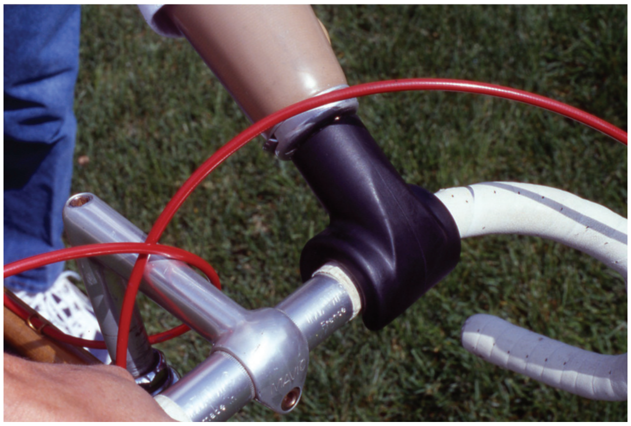

Figure 24-28. Bicycle accessory.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-29. Prehensor with spinning reel.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-30. Fishing rod prosthetic adaptor.
Photograph: Courtesy of Texas Assistive Devices LLC, Brazoria, Tex.

Figure 24-31. Universal Handle Holder (fishing rod application; Texas Assistive Devices LLC, Brazoria, Tex).
Photograph: Courtesy of Texas Assistive Devices LLC, Brazoria, Tex.

Figure 24-32. Rubber slip-on reel handle grip accessories.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-33. Crank adaptor.
Photograph: Courtesy of Texas Assistive Devices LLC, Brazoria, Tex.

Figure 24-34. Prehensor with fly fishing rod, reel, and line. Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-35. Prehensor with 44-magnum pistol. Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-36. Over and under shotgun with fore-end modification and prehensor.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-37. Pump style shotgun fore-end modification.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-38. Side-by-side style shotgun with fore-end modification.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-39. Gun turret prosthesis with over-and-under shotgun.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-40. Gun turret used with an M-16.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-41. Gun turret used with a carbine.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-42. Tool/gun cradle adaptor.
Photograph: Courtesy of Texas Assistive Devices LLC, Brazoria, Tex.

Figure 24-43. Prosthetic hockey accessories.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-44. Ski/fishing prosthesis.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-45. Ski accessory (extended for pole plant).
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-46. Nordic and alpine ski prostheses.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

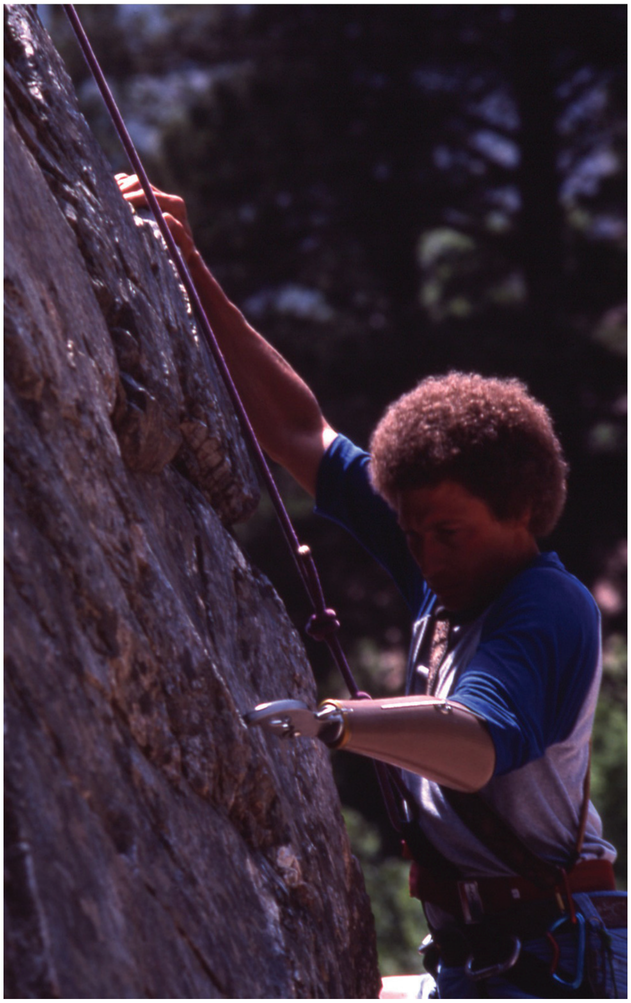

Figure 24-47. Prehensor used for technical climbing.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-48. Modified split hook for climbing by Pete Davis, accomplished amputee climber.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

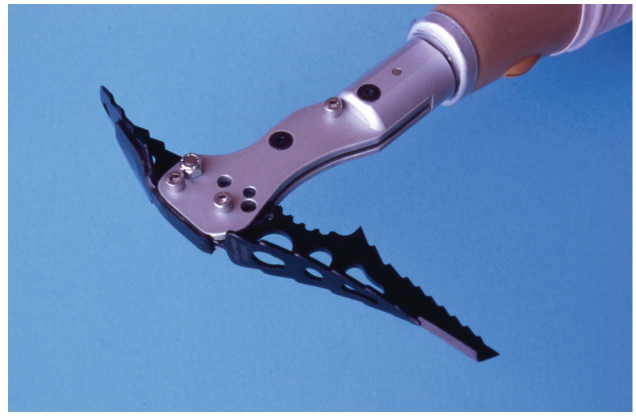

Figure 24-49. Mountaineering device custom built for Aron Ralston, who gained notoriety after amputating his lower arm that had become trapped by a boulder while he was climbing in Blue John Canyon, Utah.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

Figure 24-50. Technical climbing prosthesis custom built for Aron Ralston.
Photograph: Courtesy of TRS Inc, Boulder, Colo.

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