Lecture # 10

Artificial Limbs I

Prosthetic Options for Persons with Upper-Extremity Amputation

PROSTHETIC OPTIONS

Depending on the patient's situation, the prosthetist and rehabilitation team can make a number of recommendations. These include not providing a prosthesis, providing a passive prosthesis or cosmetic restoration, designing a conventional body-powered system, or providing a sophisticated myoelectrically controlled prosthetic limb with multiple components.

No Prosthesis

A significant percentage of patients with upper-extremity amputations elect not to use a prosthesis on a regular basis. In many cases this decision can be traced to a poorly conceived or executed prosthetic device that was provided early in the patient rehabilitation process. Some potential wearers report that the devices they have been exposed to are uncomfortable, heavy, and too slow during use or difficult to don and suspend. The advent of advanced materials has enabled prosthetists to build lighter, stronger, and more comfortable systems, as well as extremely cosmetic restorations. Despite these advancements, not all individuals with amputations integrate a prosthesis into their body image. The prosthetist or rehabilitation team should follow patients who choose not to use a prosthesis initially at regular intervals (often yearly) to ensure that their functional needs are being met. Given the rate of technological development, new components or devices are likely to become available to address problems the patient might have had at an earlier time.

Passive Prostheses and Restorations

This category of prosthesis consists of systems that do not possess the ability to actively position a mechanical elbow in space or actively provide grasp and release function, or both. The absence of these properties does not, however, render the prosthesis as passive as the name would suggest. These devices are extremely functional in terms of supporting objects or stabilizing items during bimanual tasks and activities, especially for young children with congenital deficiencies. These systems most frequently have a self-suspending design and use a realistic hand as a TD. Suspension is achieved either with specific socket interface geometry or suction negative pressure. The absence of operational mechanical components generally results in an extremely lightweight prosthesis.

The finish of these devices varies widely. Production latex cosmetic gloves provide a cost-effective medium for many patients. Many individuals, however, seek out more realistic restorations (Figure 1). These restorations require substantially greater investments in time and financial resources. This investment is most often rewarded with an extremely aesthetic, very natural appearing device. Silicone is the media of choice for these cosmetic limbs, primarily because it is practically impervious to outside contaminants. Where latex readily stains and deteriorates in ultraviolet light, silicone does not mark and, for all practical purposes, is inert. Generally, the additional cost of silicone is mitigated by its superior cosmesis, durability, and increased coefficient of friction.

Laser scanning and computer modeling to create near perfect "mirror " images of high level amputations , such as shoulder disarticulations, and scapulothoracic amputations (see Figure 1, A).

Figure (1): Passive prostheses and restorations (A, Courtesy CPS, Branford, CT; B, Courtesy Alternative Prosthetics).

Conventional Body-Powered Systems

Conventional (body-powered) systems include any prosthesis that uses a control cable system to translate volitional muscle force and shoulder or arm movement to operate a TD or prosthetic elbow. The patient must use specific strategies in order to effectively create enough excursion in the cable to control the TD or preposition the forearm in space. In most instances the glenohumeral joint contributes the largest amount of excursion in conventional prosthetic control. Glenohumeral flexion typically has more than ample excursion and satisfactory power to provide useful motors for this type of control. Additional excursion can be achieved through scapular and biscapular abduction (scapular protraction). These secondary movements allow a well-trained and skilled prosthetic wearer to increase the functional work envelope, the space in which the wearer can effectively control the TD.

For most conventional upper-extremity prostheses, the functional envelope is limited to a relatively small area below the shoulders, above the waist, and not far outward past shoulder width. Many prosthetic wearers have significant difficulty with tasks that involve grasp-and-release tasks above the head or down near the feet. Because the control strategy involves generating cable excursion through flexion or protraction, or both, tasks and activities occurring behind the back are impossible. Despite these functional limitations, conventional prostheses have provided many patients with reliable and durable prosthetic systems.

Figure-of-Eight Suspension and Control Cable

The foundation of all conventional body-powered prostheses is a harnessing system that provides both a firm anchor for the control cables and, in many cases, a stable means of suspension. Most conventional systems use a figure-of-eight– style harness (Figure 2). The terminal ends of the figure-of eight are formed by means of an axillary loop that is fit over the opposite shoulder, a control attachment cable, and an anterior suspension component on the amputated side. Most prosthetists recommend that the center of the figure-of-eight be positioned just below the seventh cervical vertebra and slightly toward the sound side. The straps of the two axillary loops can be mobile by means of attachment to a circular ring or fixed with a sewn cross point. The use of a center ring often makes the donning process less difficult and appears to provide the most satisfactory ROM. Harnessing materials are most frequently constructed of medium weight Dacron webbing with both leather and plastic integrated components.

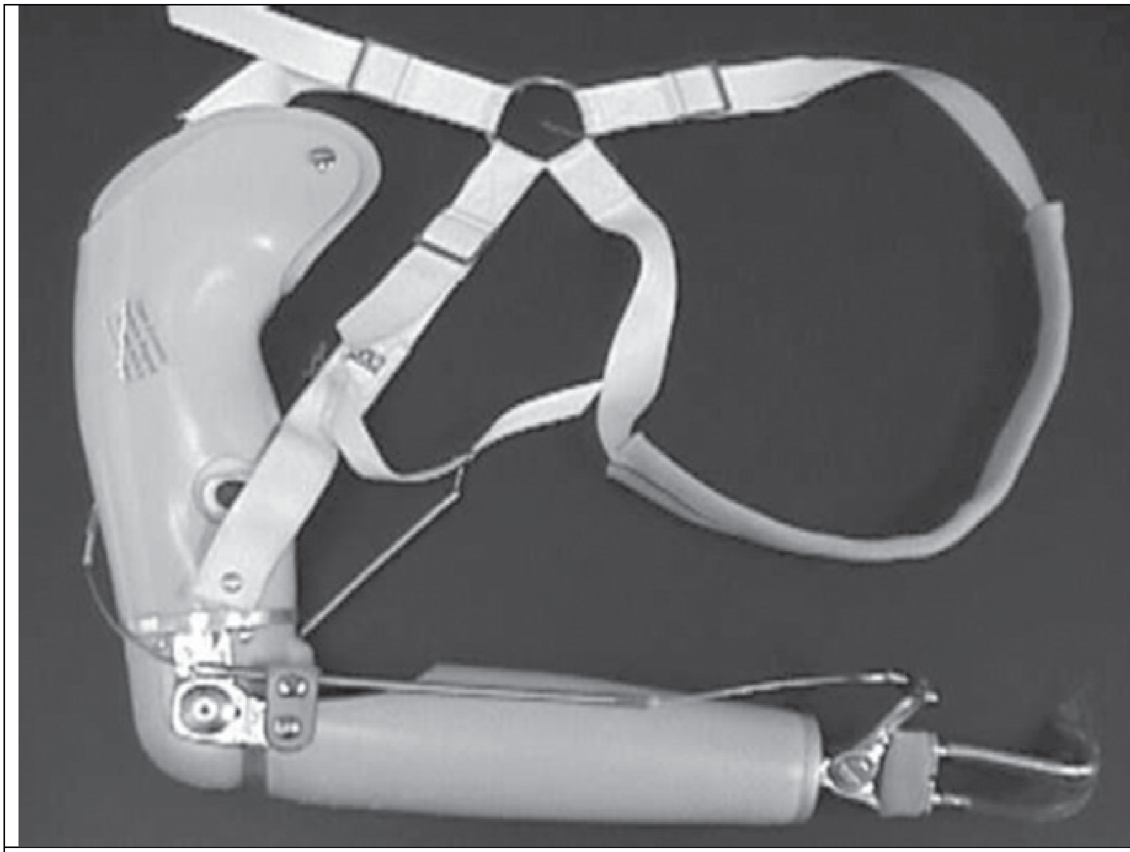

Figure (2): The figure-of-eight harness with posterior ring and cable control systems used in a conventional (body-powered) transhumeral prosthesis includes an anterior suspension loop (A), the contralateral axillary loop (B), a cable to control locking and unlocking of the elbow mechanism (C), and a cable that will lift the forearm if the elbow unit is unlocked or operate the terminal device if the elbow unit is locked (D).

Cable Control for Self-Suspending Sockets

If the prosthetist recommends a self-suspending socket, the anterior suspension of a figure-of-eight harness is not necessary. In these instances a figure-of-nine harness, consisting mainly of the contralateral axillary loop, is used to minimize cumbersome harnessing while still maximizing a firm anchor for the control cable. Self-suspending sockets may be of an anatomically contoured design or that of a flexible silicone interface, with either a locking or suction valve mechanism.

Control and Suspension for Bilateral Prostheses

For patients with amputation of both upper extremities, careful clinical consideration must be given to achieving an easily donable and highly functional prosthetic system. Instead of using a traditional figure-of-eight harness with a contralateral axillary loop for each prosthesis, the two anterior suspension components are linked. In this arrangement, the bilateral prosthetic system is effectively stabilized by the equal counteracting forces from each prosthesis. On the basis of the patient's functional needs, the prosthetist may use either a single- or dual-ring system to maximize the efficiency of the conventional prostheses (Figure 3). The second ring in the system, mounted below the primary ring, is used exclusively for the control attachment straps. The more proximal ring is used for the anterior suspensor straps and, for patients with bilateral transhumeral residual limbs, the connection of elbow locking straps.

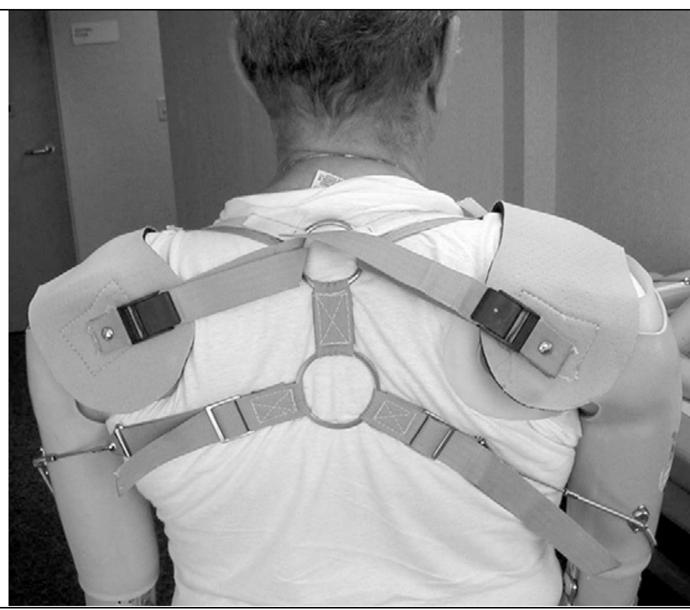

Figure (3): The harness system used for conventional (bodypowered) bilateral transhumeral prostheses includes an upper ring that stabilizes the prostheses on the trunk and a lower ring that anchors the cable control systems

Some patients with bilateral amputations opt to use separate and completely independent harness systems for their prostheses, especially if they sometimes wear only one prosthesis or if their prostheses are dissimilar. An individual with bilateral transradial amputations, for example, might elect to use a conventional cable-driven system on the nondominant side and a self-suspending externally powered prosthesis on the dominant residual limb.

Triceps Cuff in Conventional Transradial Prosthesis

Individuals with transradial amputations using a conventional harness suspension control the TD by means of a single cable. In most instances a triceps cuff is used to secure the cable housing in an optimal position, as well as provide an integral link to the forearm section (Figure 4). Several mechanisms of connection are available between the triceps cuff and the forearm. Flexible Dacron hinges provide satisfactory suspension and ROM for most midlength transradial amputations. Steel cable hinges can be substituted in circumstances where extremely heavy axial loads can be expected (i.e., if a wearer must carry or move heavy objects at work). For those with short and extremely short transradial amputations, metal hinges provide better medial lateral stability at the elbow, as well as functional stop at full extension to protect the residual limb.

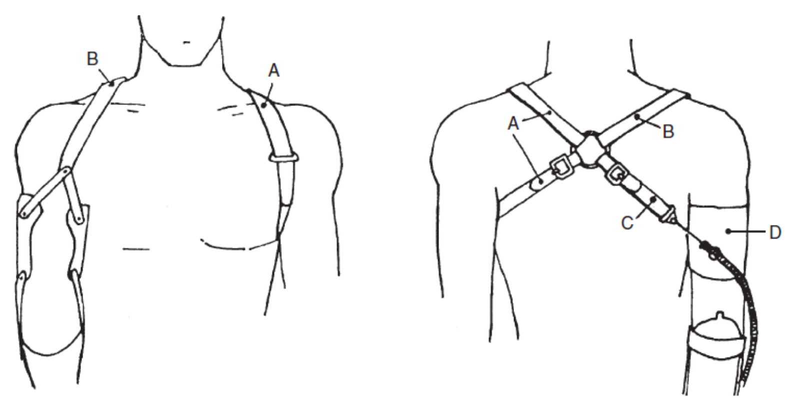

Figure (4): Anterior and posterior view of a figure-of-eight harness system for a transradial prosthesis, with the axillary loop (A), the anterior support strap that provides stability during a downward pull (B), the attachment strap for cable control of the terminal device (C), and the triceps pad that anchors the control cable in the most effective position (D).

Cable Systems to Control a Prosthetic Elbow

Patients with transhumeral amputations need a dual-cable system; an anterior cable controls the locking and unlocking of the elbow mechanism, while the other cable controls the TD (if the elbow is locked) or moves the prosthetic forearm (if the elbow is unlocked). The second (longer) cable that attaches to the TD requires a split-cable housing system. The proximal portion of the housing is attached to the humeral section, while the distal portion is attached at a location and height anterior to the elbow center.

Most elbow mechanisms have multiple locking positions at equally spaced intervals moving from full extension to flexion. The locking mechanism is most frequently activated using a rapid and forceful shoulder extension and abduction (Figure 5). When the elbow mechanism is “locked” in any given position, this quick down and back movement elongates an anterior cable that releases the lock; subsequent shoulder flexion or scapular abduction (protraction) affecting the posterior cable repositions the prosthetic forearm in space. This happens because the cable running to the TD is aligned anterior to the axis of rotation of the elbow mechanism; when the elbow is unlocked, tension through this cable causes the forearm to rise in flexion. When the forearm reaches the desired inclination for the task at hand, another quick down and back motion will reengage the lock. Once the elbow mechanism is locked, cable control is transferred to the TD, and subsequent shoulder flexion or protraction operates the prosthetic hook or hand. Because this control strategy is always sequential in nature, careful consideration and assessment must be given to the force excursion ratio. Failure to maximize these criteria results in incomplete elbow flexion or incomplete TD control.

Cables and Cable Housings

For both transradial and transhumeral prostheses, the cable and housings should traverse as straight a path as practical. An abrupt or sharp radius creates excessive and unnecessary drag as the cable passes through the housing. The mechanical efficiency of the system is critical to successful operation, particularly for those patients with limited strength or ROM. Steel cable has been used successfully for many years in prosthetic practice. Steel cable is available in several thicknesses so as to meet the needs of all types of users.

Clearly the heaviest cables are well suited to heavy-work applications and are often used for individuals wearing prostheses for both upper extremities.

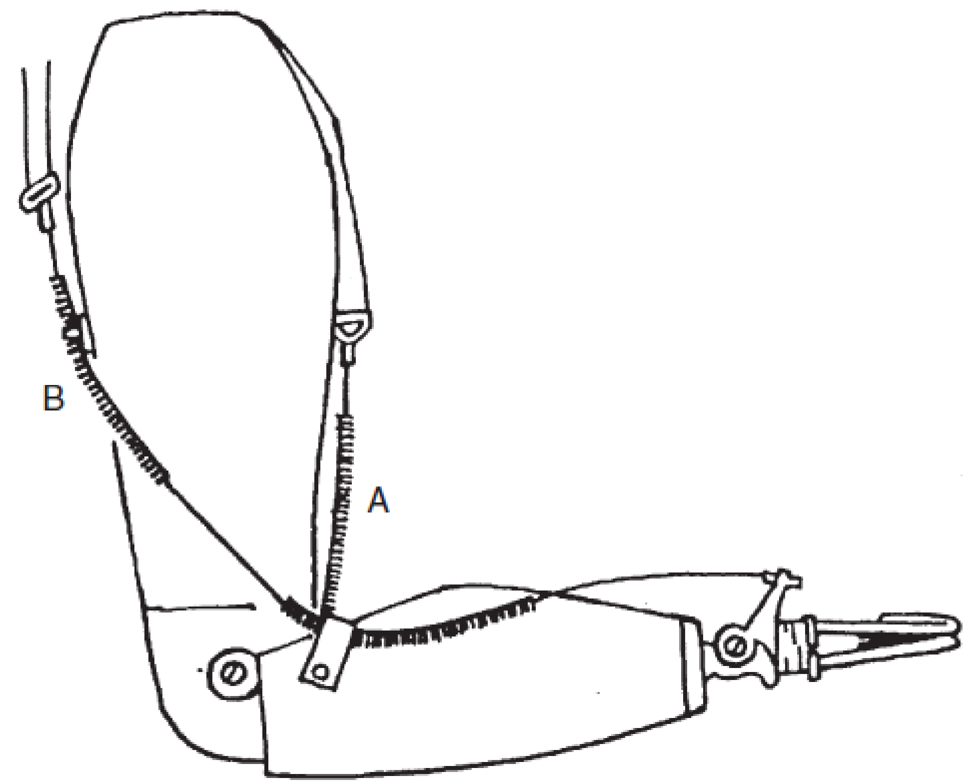

Figure (5): Dual control cable and lift loop of a conventional (body-powered) transhumeral prosthesis. Quick and forceful downward and backward shoulder motion operates the elbow locking and unlocking mechanism via the anterior cable (A). The second cable system (B) operates the terminal device if the elbow is locked or lifts the forearm if the elbow is locked. This occurs because the TD control cable is positioned anterior to the axis of the mechanical elbow joint.

Low-friction linings are often added to the interior surfaces of the cable housing to improve the mechanical efficiency. This technique effectively decreases the coefficient of friction of the stainless cable as it passes through the metal cable housing. Typically, the low-friction linings wear and require replacement before cable failure.

Recently, nonmetallic cable media with both high strength and low coefficients of friction became available; these improve mechanical efficiency and daily wear characteristics of the prosthetic system. When nonmetallic cables are used with low coefficient linings, the result is often an extremely smooth and highly efficient cable system. These nonmetallic cable alternatives are not mechanically swedged to the attachment hardware used at each end of a prosthetic cable system. Instead, cable connections are made by using highly specialized knots that provide a reliable connection with a smooth profile. Should a nonmetallic cable fail, it is possible for the wearer (with some assistance) to complete emergency repairs without returning the facility. Furthermore, nonmetallic cables do not leave dark residue and stains typically associated with steel cables.

Although these nonmetallic cables are every bit as strong as their steel counterparts, one important drawback is that they do not provide any indication that the cable is nearing the end of its service life. Conversely, steel cables typically become rough and begin to drag as the individual strands of the cable part. Despite this single drawback, nonmetallic cables are strongly recommended in most clinical applications. Further consideration should be given to provide all patients with additional backup cables for times when immediate access to prosthetic repair services is not available.

TERMINAL DEVICES FOR CONVENTIONAL PROSTHESES

The TDs most often used for conventional body-powered prostheses are either a hook (Figure 6) or hand (Figure 7). Both are available as a voluntary opening system (the TD is closed at rest, and the wearer opens the hand by means of the cable) or as a voluntary closing system (the TD is open at rest, and the wearer closes the hand by means of the cable). Each configuration has its own inherent strengths and weaknesses.

Voluntary opening devices enable the wearer to apply volitional force and excursion of the cable (using shoulder flexion or abduction) to open the TD. Once tension is released from the cable system, the object being grasped is “trapped” in the device, allowing the wearer to position the object in space as the task demands. The prehensile force (grip strength) is dictated by some external closing mechanism, most frequently springs or elastic bands (see

Figure (6). Significant prehensile forces can be generated by using multiple layers of elastic bands or multiple springs but must be matched to the wearer's ability to create and sustain cable excursion. Because grip strength is determined by the number of elastics or springs used, it is constant and cannot be voluntarily modified when handling heavy or fragile objects. The mechanical inefficiency and friction inherent in a cable control system increase the force necessary to open the TD above the closing force achieved by the rubber bands or spring systems. Finding the right combination of external closing mechanism strength and user's motor control and excursion for the many different daily functional tasks can be challenging. Several manufacturers market voluntary opening prehensors with settings the wearer can adjust to light or forceful grip strength.

In voluntary closing TDs, the volitional force and excursion supplied by the wearer closes the TD from its normally open position. The key advantage of a voluntary closing TD is the ability to volitionally grade prehensile force, adapting it to the characteristics of the object to be held. When a voluntary closing TD is used, significantly higher forces can be applied through the cabling system. In fact, with most voluntarily closing TD and cable systems, voluntary prehensile force is limited only by the motor powers available from the wearer or by discomfort of the residual limb. In this control strategy the patient must maintain both excursion and power so as to retain the object in the TD.

Voluntary closing devices are not often chosen for individuals with transhumeral amputations because the limited cable excursion available to them is also being used to preposition the forearm in space. Functionally, much of the cable excursions would be used to close the TD so that less would be available to move the forearm. Although those with transhumeral amputation frequently have adequate motor control to position the forearm in space, many are quite challenged to produce enough excursion to effectively operate the elbow throughout full ranges of motion while maintaining a graded prehension of the TD. These actions become even more challenging if the residual transhumeral limb is relatively short. The external passive closure of a voluntary opening TD tends to be more functional for these individuals. Because cable excursion is typically limited for those with bilateral amputations, voluntary opening devices are also the TDs of choice if bilateral conventional prostheses are recommended.

A

B

Figure (6): Various conventional "hooks" are available to meet the functional needs of individuals using conventional (bodypowered) prostheses. The top row of these voluntary opening terminal devices, designed for children, has a "thumb post," as well as coated grip surfaces that are held closed by rubber bands at the base of the hook. Adult hooks are available in a number of configurations to meet the functional and vocational needs of the wearer. B, Terminal devices have also been designed for occupations that require stabilizing objects, carrying objects, or holding cylindrical or spherical objects.

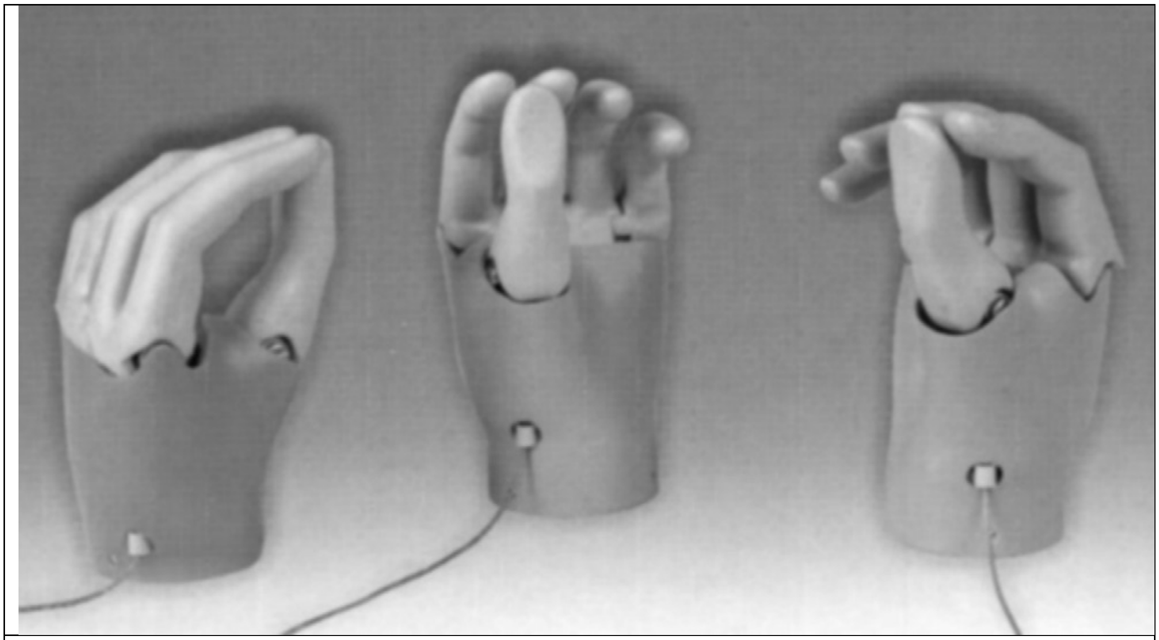

Figure (7): Examples of mechanical hands for a conventional (body-powered) prosthesis. Tension of the cable opens the hand to grasp an object using a mechanical "three jaw chuck" grasping pattern. Release of tension on the cable passively holds an object between the thumb and first two digits. To release a held object, the wearer applies tension to the cable once again, to open the mechanical hand. The fourth and fifth fingers are passive and prepositioned in slight flexion but are not part of the grasp and release function of the mechanical hand.

Socket Configurations

The transhumeral and transradial prosthetic sockets used in contemporary prosthetic practice have evolved from nonanatomically and functionally based designs to highly contoured, skeletally correct and intimately fitting designs. A significant portion of these anatomically contoured socket advancements have come as a direct result of changes in material technology. Until recently, upper-extremity prosthetic sockets were fabricated using thermal setting resins for structural integrity and finish. By nature these materials were hard and did not yield effectively to changes in muscle contour as the wearer used the limb in functional activities. With the advent of moldable thermoplastics and advanced anatomically contoured socket designs, improvements in intimacy of fit and functional ROM have been achieved.

Most contemporary upper-extremity prosthetic sockets use some type of flexible interface with a rigid frame exterior. The interface material is often composed of a high silicone content elastomer. These elastomers have dramatically improved patients' perceptions of fit and function with regard to comfort.

Socket Transradial Self-Suspending Sockets

Many patients with transradial amputations are now fit with self-suspending sockets that both increase functional ROM during activity and, more importantly, improve wearer acceptance and compliance. Highly specialized bone and muscle contour promote effective control in both conventional body-powered and myoelectrically controlled prostheses. Historically, self-suspending transradial sockets encase the medial and lateral humeral condyles to provide suspension. 34 The nature of this medial-lateral compression inherently decreased ROM, particularly in terminal flexion. New designs are becoming less dependent on the condyles and are using higher anteroposterior forces between the anterior fossa and olecranon of the elbow to achieve suspension. This strategy increases the wearer's ability to fully extend the elbow.

Advances in Donning Techniques

As the intimacy of socket designs has increased, so has the need for more effective donning techniques. Historically, cotton stockinettes or elastic bandages were adequate for drawing tissue into prosthetic sockets and allowed for satisfactory donning.

Because these materials have high coefficient friction, they can be difficult to pull from the socket. High friction also can be fairly abrasive on the wearer's residual limb. A new generation of pull socks made of low-friction cloth have been developed. Many have coatings impregnated into the cloth during manufacture to allow for effective, nonabrasive donning of intimately contoured prosthetic sockets. With the initial tension as it is first pulled through the opening in the socket, the pull sock encases the soft tissue of the residual limb as if it were a cylindrical cone. As the pull sock is drawn through the opening, it positions the soft tissue of the residual limb as intended by the contour of the socket. These donning tools have also enabled some individuals with bilateral amputations to independently don aggressive self-suspending sockets.

Advances in Transhumeral Socket Design

Whereas the traditional transhumeral prosthesis had an over the- shoulder cap socket design, recent advances in socket design have resulted in sockets with lateral trim lines below the acromion process. The additions of anterior and posterior stabilizer extensions that cross toward the midline on the amputated side provide superior rotational stability.