Upper-extremity prosthetic fitting presents a variety of unique challenges to the prosthodontist and client alike. Unlike other prosthetic levels that are more passive in nature, prostheses for the upper extremity require a high degree of function for gripping and lifting objects. At the same time, because the upper extremity is more visible, cosmetic concerns are more significant. Unfortunately, these cosmetic allowances also affect overall function so a balance between the two must be established.

Because upper-limb prostheses are typically operated by complex cables or electronic systems, clients will require training to become proficient at controlling them. In addition, to allow normal movement of the upper extremity, which has a wide range of motion, the restriction caused by the prosthesis must be kept to a minimum. Finally, the upper-extremity prosthesis often requires the use of a harness that must be custom fitted to optimize function and increase suspension comfort.

**Early Fitting**

If the upper-extremity client is not fitted within the first two months, rejection of the prosthesis is more likely to occur. Fitting during this “Golden Fitting Period” is imperative, especially with shorter amputations so that the client continues to incorporate the prosthesis in two-handed activities. If an arm has too many controls and devices the patient may become frustrated with using it, often referred to as “gadget intolerance.” Sometimes a patient is fitted with a special prosthesis right after the amputation surgery called an “Immediate Post-Operative Prosthesis,” so that training can begin immediately.

Children should be fitted with their initial passive prosthesis when they begin to sit up, which can be as early as 3 months of age. This is when the child begins to use his or her hands together for two-handed gripping activities. Early introduction incorporates the prosthesis in the child’s body image, which increases child and parental acceptance of the device. The prosthesis is then activated when the child becomes more accustomed to its use – at about 1-1/2 years of age for below-elbow amputees and 3 years of age for above-elbow amputees.

**Evaluation**

Before componentry can be discussed, the mindful prosthodontist must meet with the client to discuss his or her functional and cosmetic needs, activities at work and hobbies. Componentry advantages and disadvantages will then be shown relating to functional and cosmetic goals. If the client is a child, parents can also use the evaluation to receive information and guidance regarding the prosthesis. Once the prosthodontist, client, and parents agree on the componentry for the terminal device (hook or hand), wrist, construction, elbow, hinges, control, socket, and harness, the fitting process can continue.
The prosthetist will then examine the limb to see its general shape and to look for any scarring, sensitivity, and bony areas. Clients with congenital limb deficiency will be extremely load-tolerant since they have never experienced amputation. Their muscle arrangement may be unique, which relates to issues with control sensors (called myosites) for electronic arms. Assessments of range of motion and muscle strength will be recorded to determine how the socket will be made and how to avoid any possible restriction of movement.

**Componentry selection**

Many prosthetists and amputees alike engage in a discussion of prostheses in the context of high- or low-tech. The real key is weighing the advantages and disadvantages of both systems to provide the most appropriate technology for the individual.

**Body-powered systems vs. external-powered systems**

Body-powered cable systems work by using the patient’s body movements through a harness to operate the prosthesis. Typically, the patient moves the arm forward or rounds the shoulders to pull the cable and operate the prosthesis. These systems, derived from bicycle controls, are relatively lightweight, inexpensive, and easy to repair. In addition, they transfer loads to the harness and can give the amputee good biofeedback as to where the prosthesis is in space. The main disadvantages are their appearance and their dependence on the amputee’s physical ability.

Since externally powered prostheses are self-contained, they eliminate harnessing and activation cables. Because they more closely resemble the anatomic arm without cables or harnessing, they are cosmetically acceptable to the new amputee. While cable systems require strength and body movements, external systems minimize body movement requirements with myoswitches (muscle sensors) or push/pull switches. This makes them especially useful in juvenile or high-level amputation cases where strength and excursion are issues. External-powered systems can also deliver higher pinch forces of 24 pounds, while body-powered systems, dependent on the number of rubber bands for grip, deliver about 5-10 pounds. Unfortunately, externally controlled systems usually cost three times more than body-powered devices, and batteries and motors add substantial weight to the end of the prosthesis, which increases the suspension requirements. Both body-powered and external powered systems require adjustment and fine-tuning with respect to cabling and harnessing to optimize use. Although modern electronic control systems are much more durable than they were in the past, repairs are still fairly expensive, compared to those for body-powered systems.

**Terminal devices**

Terminal devices are so named because they are at the end of the prosthesis. Because they serve as the primary functional prehensor, they receive more attention with regard to the patient’s vocational and recreational needs. Terminal devices can be separated into four categories: passive hands, split hooks, mechanical hands, and specialized tools.

Passive terminal devices are primarily hands with bendable or spring-loaded fingers that place special emphasis on cosmetic value. Most use standard cosmetic gloves while other more expensive designs are made to match the coloring and shape of the other limb in detail including freckles and hair. A variety of cosmetic glove styles are available in PVC or silicone. These gloves must be replaced as they become soiled or worn. Although passive and/or cosmetic terminal devices have no gripping action, they do provide significant functional value to the unilateral prosthetic user as a holding and positioning aid.
The most often used functional terminal device is the split hook. It is popular because it provides lateral gripping and precise manipulation at the tip. Most are canted to one side to provide better visual feedback and have neoprene lining to grip metal objects. Although only a few types of hooks predominate, over 30 different hook configurations are available to meet the special needs of the prosthetic client.

Mechanical hands are used for greater cosmetic appeal and as an alternative grip pattern. Almost all hands (including externally powered hands) have a three-jaw chuck or palmar prehension pattern using the thumb and first two fingers. This serves multiple functions and allows users to pick up small objects at the tip and cylindrical objects toward the web of the hand. Although these mechanisms are more cosmetic than hooks, they provide little real functional benefit. The stiff internal spring mechanisms are less efficient than hooks and require substantially more effort to open. Still, hands are preferred in many instances where cosmetic concerns outweigh pure function. For this reason externally powered hands are considered much more functional. Many prosthetic clients choose to have both hook and hand terminal devices with a special wrist that allows an easy interchange between the two.

Some terminal devices, designed for singular purposes, resemble tools more than multifunctional designs. Special terminal devices have been made for a variety of activities, including golf, photography, bowling, baseball, swimming, and fishing. Others allow the user to snap various hand tools and kitchen utensils onto the device to perform certain tasks. The obvious disadvantages are that sometimes the proper tool may not be available and sometimes the user may have a tool attached for one task when he or she needs to do another.

Electronic terminal devices come in hook styles, but are most often requested as hands. The motor systems have two functions: fast clasping and firm gripping. As the hand grasps an object it "downshifts" and grips the object tightly. Newer developments in electronic hands have increased responsiveness and offer a variety of sensors that detect loads and environment.

Prosthetic wrists

The prosthetic wrist functions to attach the terminal device to the prosthesis and provide forearm rotation positioning. Most wrists provide simple passive frictional rotation control by positioning the terminal device with the other hand or against a table or chair. Other designs have special features for disconnection, flexion, rotational lock, and active positioning. Flexion wrists provide standard passive friction control and lock the wrist into three different positions when a lever is released. This function is especially important for bilateral amputees who must reach the midline for activities of daily living. Many prosthetic users choose to have at least two different types of terminal devices such as a hook and a hand. Quick-disconnect wrists allow them to easily interchange between the two without removing their prosthesis.

Construction

Exoskeletal construction implies that the structure of the prosthesis comes from the outer layer. This involves making the interface or socket out of soft plastic or laminated resin. Foam or wax is built up to form the shape of the arm. A reinforced composite frame is made of laminated resin that is incorporated into the wrist or elbow attachment. The use of wax allows the prosthetist to melt it out after the shape has been laminated leaving an inner cavity. This method is often used to create space for the controls and battery in electronic prostheses. Endoskeletal designs, on the other hand, use internal tubing structures with external soft foam covering. The surface durability
is not as high as that of an exoskeletal design, and the prosthesis must be considered a lighter duty arm. This system is also very popular for high-level fittings because of its light weight and the patients’ lower lifting requirements.

**Hinges**

Prosthetic hinges function to attach the below-elbow socket to the upper harness without impeding normal elbow function or range of motion. Flexible hinges are primarily constructed of nylon webbing attached to an upper-arm pad. This preserves forearm rotation, which is especially important for longer limb lengths and bilateral clients. Single-axis hinges act as a pivot between the interface and an upper-arm cuff, but eliminate forearm rotation. They are used on shorter limb lengths where forearm rotation is minimal and on heavy-duty prostheses because they distribute the loading to the upper arm. Special hinges that lock or magnify range of motion of the elbow are available for shorter or fleshy limbs.

**Elbows**

Elbows may be positioned with friction, cable locks, or electronic controls. Passive elbows are simple lightweight devices that are prepositioned by the amputee and provide little loading ability. They are frequently used with cosmetic prostheses, lightweight endoskeletal systems, or higher-level amputations where the user cannot actively control the prosthesis. The locking elbow is the most commonly used elbow for body-powered prostheses due to its durability and ease of use. The elbow is raised with the cable system and locked with a backward motion. Then the terminal device can be used. Some elbows have a spring-loaded feature that helps lift the forearm into position. Electronically, the elbow can be controlled with muscle sensors or switches. When the forearm is raised and held stationary for a short period, the electronic control switches to hand control. Some electronic designs are stronger and faster depending on the type of motor system they use, but they are also more expensive. The prosthetist may choose to use a mechanical elbow and electronic hand called a “hybrid system.” This has the advantage of lower cost, lighter weight, and faster positioning while garnering the superior pinch of the electronic hand.

**Shoulder units**

Shoulder joints are used primarily to aid the patient in getting dressed and passive positioning. Most shoulder joints are passive in nature, but a design is available that can lock into position. The friction that controls arm movement forward and upward can be adjusted.

**Control cable and harness systems**

The control cable and harness system work together to provide two main objectives. The first objective is to suspend the socket on the residual limb. In doing so, the harness must be adjusted to the patient’s form, distribute the load, and be stable in all normal positions. The harness must also be easy to don and doff so the client can put it on and take it off with minimal help. The objective of the cable system is to transmit force from the body movements to the prosthesis for operation of body-powered components. This must be done with minimal interference of the components and minimal control complexity. The control movements used must be independent of one another and be operable by relatively inconspicuous body motion. There are many different designs of harnesses that are custom made for the amputee, but all follow a few types.

**Socket design**
The prosthetist must also decide which type of socket suspension to create. Most common designs rely entirely on the harness for suspension. Some below-elbow designs, called “self-suspending,” fit intimately over the elbow, yet allow normal movement. Above-elbow design variations that distribute some of the added loading of external-power prostheses are much tighter and require the patient to pull into the socket. Both involve wrapping a sock over the limb and pulling the sock through a hole in the socket. The socket is actually made smaller so that the limb shape and the limb tissue compress and hold the prosthesis on. Silicone suspension, in which a soft pliable sleeve of silicone is rolled onto the arm, can also be used. An attachment pin locks into the bottom of the socket. This system works very well for above-elbow clients, those with fleshy limbs, or where self-suspension does not work.

Measurement & casting

To create the socket (or interface), the prosthetist must wrap the residual limb with plaster wrap. In preparation, the prosthetist will then coat the limb in a separator or jelly to allow easy removal of the cast and pull a tube gauze casting garment on the limb. This is secured with an elastic strap and the client will be instructed how to hold his or her limb. At this point, the prosthetist will measure the length of the residual limb and measure the opposite side so that the prosthesis will match the opposite arm. Also, the prosthetist will measure around the amputation in several places to help recreate the volume of the socket. Marks will be made with ink pencil where the measurements are made and where the subsurface bony areas are. The prosthetist then wraps the plaster gauze on the residual limb to create an accurate cast of the patient’s limb. The prosthetist pushes on the plaster cast to load soft, load-tolerant areas and relieve sensitive or bony areas. After the cast is removed, it is filled with liquid plaster, which recreates the shape of the arm. The ink marks drawn on the limb are transferred from the cast and then to the filled mold.

Modification of the mold

After the plaster has hardened, the prosthetist will remove the plaster wrap to expose the positive model of the limb. The prosthetist then takes the mold of the arm and removes plaster from the soft areas with a file and adds plaster to bony areas. This requires a certain amount of skill and experience on the practitioner’s part to create a comfortable socket. It is important that the socket fit tightly enough to resist rotation and stay on the arm when loaded, but not so tightly that it causes pain or decreases range of motion. Because this surface forms the inner surface of the socket, extra time is taken to smooth the mold. The modified mold will look different from the anatomic arm, but will create the best-fitting socket.

Check Socket

Once the socket has been modified, clear plastic is vacuum formed on the plaster model to create a check socket. This check socket is used to assess the fit of the socket and to make adjustments easily. If any areas cause discomfort, the prosthetist can use a heat gun to soften the plastic and push it out. Also the trim lines of the socket may be cut, lowered or flared away for better range of motion and comfort. It is important that the clients be detailed in their evaluation of the check socket because it is much more difficult to make these adjustments after the final prosthesis is created. Once the optimal socket shape has been agreed upon, the prosthetist will make alignment marks, which indicate how the prosthesis should hang on the arm in order to reach the mouth. Electric arms may be assembled “in the rough” to check function and how the weight of the arm affects socket fit. This is crucial to check the position of the electronic muscle sensors (myosites). After a good fit and alignment have been established the construction of the definitive prosthesis can begin.
Fitting of the definitive prosthesis

The final prosthesis is constructed from the mold of the check socket by laminating plastic resin with reinforcing materials like carbon fiber and Fiberglas. This creates a lightweight, yet extremely strong, construction. The interface is sometimes made of softer, more flexible plastic that can bend at the trim lines. Fitting an upper-extremity prosthesis can take a long time because of all the devices, buckles, straps, and electronics that must be fitted and adjusted. It is important that the prosthetist take his or her time to ensure optimal performance. First, socket fit will be checked and adjusted if needed, and then the prosthesis alignment will be examined. Electronic arms will be attached to a monitor to check placement and performance of the muscle sensors when the arm is fully loaded. The cable system for the body-powered system will be connected to the terminal device, elbow, and harness attachment. It is important that the prosthetist check the function of the componentry and any possible interference to ensure good operation. The control harness is constructed of straps that wrap around the body to hold the arm on and to operate the cable system. This is somewhat uncomfortable to the new client and strange to children. The prosthetist will instruct the client on all the functions of the prosthesis and closely watch the client perform these activities. Adjustments will be made to the electronics to achieve control balance, and placement of the cable system will be checked to ensure easy movement.

Upper-extremity therapy and training

At this point, the client will become much more involved. The occupational therapist performs a significant role in the rehabilitation process. The client will begin by demonstrating the use of the prosthesis in normal everyday tasks or “activities of daily living.” Techniques for dressing, eating, and hygiene will be addressed, along with other activities such as driving, sports, and job tasks. Children may have unique needs that must be brought up by the parents since they are still learning many of these daily routines. Sometimes it is necessary to adapt devices for better access and manipulation. Zippers may need ring tabs, steering wheels may need a ring knob, Velcro shoes may be chosen, and recreational adaptations may be desired. After the therapy phase is complete, it is ideal for the prosthetist and client to meet for follow-up every month initially and every six months after that. Children must be constantly monitored to check socket fit due to growth and maintenance since they are usually extremely active users.