Prostheses

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Abstract

The primary focus for upper limb deficiency is on development, function, activities of daily living, sports, recreation, vocation, and appearance. The decision to fit a child with a congenital deficiency with upper limb prosthesis is individual and will vary from clinic to clinic and from family to family. Prosthetic options range from passive, to task specific to conventional to external power. All are based on the established objective goals and outcome expectations determined by the prosthetic team, patient, and family.

Utilization of Prostheses in Congenital and Acquired Deficiencies

Congenital limb deficiencies occur in .54/1,000 live-born infants with 45.8 % affecting the upper extremity (Makhoul et al. 2003), and the upper limb accounts for 3–15 % of all amputations (Smith et al. 2004). The major causes for upper limb deficiency are trauma (43 %), congenital absence (18 %), and cancer (14 %) (The National Amputee Statistical Database Annual Reports 2004).

Accidents with lawn mowers and motor vehicles account for the majority of acquired amputations in young children. Tumors are the most frequent cause of amputation resulting from disease in older children followed by meningococcemia and other vascular diseases.

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While the etiology of upper limb and lower limb deficiencies is similar, the approach for their prosthetic care and treatment is variable. Mobility, weight bearing, and ambulation are not the primary issue with an upper limb deficiency. The primary focus for upper limb deficiency is on development, function, activities of daily living, sports, recreation, vocation, and appearance. It is most important to keep in mind that there is no prosthetic replacement for the hand from both a sensory and mechanical sense. Bimanual tasks cannot be performed in the same manner as if the hand was present.

Upper Limb Prosthetic Team and Patient Management

Children, and their families, with upper limb deficiencies are best serviced in a family-centered clinical environment with a multidisciplinary team including a physician, an occupational and/or physical therapist, and a social worker all with experience and interest in limb deficiencies and upper limb deficiencies in particular. The other key members of the team include the patient and family. Everyone participates in the process to best discuss and determine the goals and needs of the child including but not limited to growth and development, activities of daily living (ADLs), strength, range of motion, educational/vocational needs, sports, recreation, and social growth and development. Prior prosthetic wear is also an important part of the overall team assessment and evaluation. These all help determine the overall treatment plan.

The decision to fit a child with a congenital deficiency with upper limb prosthesis is individual and will vary from clinic to clinic and from family to family. The choice for children with acquired upper limb deficiencies is not typically as variable as those children have a history of development and function with two upper extremities. Many believe that early fitting with training will lead to improved wearing patterns and ability to use the prosthesis for functional tasks (Krebs et al. 1991). Yet others feel that wearing a prosthesis, especially with a unilateral deficiency, can impair normal function and development primarily because the prosthesis eliminates the tactile sensation that the child has and is used when they perform functional tasks (James et al. 2006). The literature shows that the rejection rate for pediatric users with upper extremity prostheses is higher than for lower extremity prostheses, 38 % for passive prostheses, 45 % for body-powered prostheses, and 32 % for myoelectric prostheses (Biddis and Chau 2007). Many children and families, especially with unilateral congenital limb deficiencies, do not choose to obtain a prosthesis. Others chose to get a prosthesis and are successful wearers and users, and others chose to get a prosthesis but do not wear or use it functionally or wear it the majority of the time. Some choose to use the prosthesis for activity-specific purposes, primarily for sports, recreation, or vocation. The important thing to keep in mind is that there are no "right" or "wrong" decisions and the decision that is made at one clinic visit may change over the course of time, age, and growth and development of the child.

Parents with a child with a congenital deficiency will frequently come to a limb deficiency clinic with their newborn. They are typically looking for a prosthesis that will as closely approximate the look, feel, and function of the hand and arm. Their first visit is their introduction to the world of prosthetics and the clinical team. In addition to the physical examination, each team member will spend time with the family explaining their roles, the process and flow of the clinic, and education of the process. This visit includes discussions on treatment options, philosophies of the clinic, training and therapies, protocols, outcomes, etc. Support for the family is discussed and when needed contacts and referrals are made by the team. In many instances, talking with another family who is in clinic that day, has gone through a similar process with their child, and is comfortable in sharing their experiences is extremely helpful. All efforts are made to answer all questions. At the conclusion of the first visit, the plan of care is determined. In addition, follow-up appointments are scheduled, and any medical or therapy required is provided or scheduled.

Typically children with upper limb deficiencies are not considered for a prosthesis until they are

beginning to sit, approximately 6 months of age. The prosthesis recommended is passive (the terminal device does not mechanically open and close with a cable) and can assist with sitting balance, pre-crawling, crawling, creeping, and some opposition to the contralateral side. The terminal device on this prosthesis can be as simple as a "mitt" with no ability to hold an object or one that can be passively opened to hold onto a lightweight object like a toy or block. Potential advantage of early fitting is that it gets the child accustomed to wearing a prosthesis and the family comfortable with a child wearing a prosthesis. Subsequently, when the child is age appropriate for bimanual tasks, he or she will have good wearing patterns and tolerance (Shaperman and Setoguchi 2003).

Activation of the terminal device typically occurs between 10 and 18 months when the child is able to utilize the cable for simple grasp and release functions. Activation of the prosthetic elbow on a transhumeral or above prosthesis occurs around the age of 4–5 (Uellendahl and Gaebler-Spira 1999). It is important to keep in mind that these ages are general and activation is dependent upon cognitive, physical, and social development.

Upper limb prosthetic design: The following is a general overview of upper limb prosthetic design and components. It is not intended to be a comprehensive description of all available components and manufacturers.

Body-Powered Prostheses

The upper extremity body-powered (or conventional) prosthesis is controlled by the user by a cable and harness system that is activated with shoulder and scapular motion. It consists of a terminal device, wrist unit, forearm shell, prosthetic elbow (for a transhumeral or above deficiencies), total contact socket (molded to the residual limb), and harness with cable.

It is interesting to note there have been few changes and advances to the body-powered design. The exception is the introduction of newer materials for socket fabrication and terminal device options which are more activity specific for work, sport, and recreation.

Terminal Devices A terminal device is the most distal component on an upper limb prosthesis. Its function is to allow holding or prehension utilizing the cable and harness of the prosthesis. The terminal device is threaded into the wrist unit. The user is not dependent on one terminal device. They can be interchanged by unscrewing them from the wrist unit and replacing it with another terminal device. Typically there is one terminal device used for most tasks with the option of alternative terminal devices for activity-specific use.

Passive terminal devices are the exception to the definition above as they provide minimal, if any, prehension and are not cable activated. They provide the patient with a visual replacement for their deficiency without providing function. While not cable activated some can hold an object when placed into them, or the fingers can be passively positioned. They cannot grasp and release objects. Nor can they typically hold objects of varying sizes and weights. Infant terminal devices, as discussed about, fall into this category. Passive hands used for cosmetic purposes also fall into the category of passive terminal devices. Passive hands are available in varying sizes and are covered with a cosmetic glove which comes in various skin tones and shades. A passive hand and glove can also be custom made utilizing a model of the contralateral size with a custom-painted glove to best approximate the contralateral side details, color, tone, nail bed shape, body hair, wrinkles, etc. Custom hands/gloves can be very expensive and are not particularly durable. This can be an issue for the young child and adolescent as they grow so quickly (requiring frequent replacement) and are more apt to rip, tear, and get their glove dirty with just daily activity and play. In many instances passive prostheses are not covered by medical insurance as they are classified as "cosmetic" and "not medically necessary" (Figs. 1, 2 and 3).

Voluntary opening terminal device: A voluntary opening (VO) terminal device is closed at rest. Cable and harness activation is required to open and grip an object. Rubber bands or springs

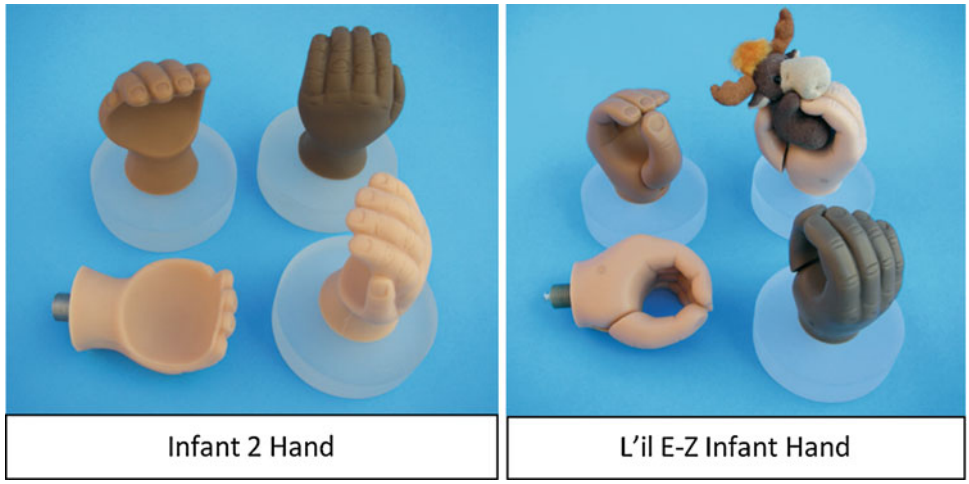

Fig. 1 TRS passive infant terminal devices

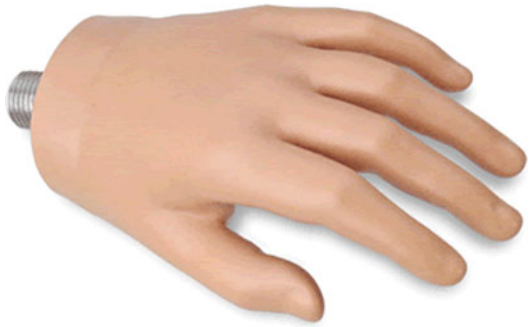

Fig. 2 Hosmer child passive hand

Fig. 3 Livingskin custom glove restoration

hold the terminal closed. To open the device, the user must apply tension through the harness and cable. Relaxing the tension will close the terminal device on the object. The amount of grip force is controlled by the number of rubber bands or the tension of the spring.

Voluntary closing terminal device: A voluntary closing (VC) is open at rest. Cable and harness activation is required to close the terminal device to grip an object. To close the device the wearer must apply tension through the harness and cable. This tension must be maintained to maintain the grip. Relaxation will open the device. For activities and tasks that require long-term or sustained grip, the option of a locking mechanism is utilized.

Hook terminal devices are the most common voluntary opening terminal device and are made of stainless steel, aluminum, and titanium. They come in various sizes and shapes depending on the intended use. Pediatric hooks are typically aluminum and are canted in shape to allow better visualization of the object in the terminal device especially for fine motor tasks (Shurr and

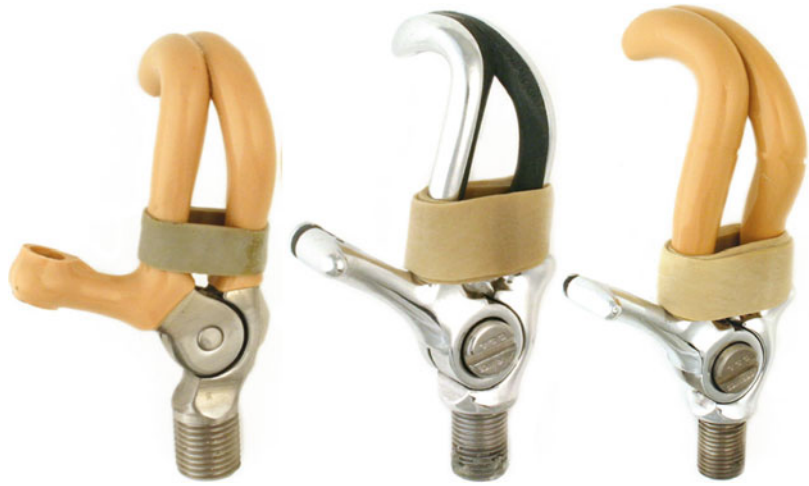

Fig. 4 Hosmer pediatric voluntary opening hook terminal devices

Cook 1990). They can also be coated or covered in a rubber material to improve cosmesis and to limit "slippage" of an object through the hook. Rubber bands around the "fingers" control the resistance to opening and closing. The more rubber bands, the heavier the object that can be held in the terminal device. But that also means the more "power" it will take to open and close the device through the cable and harness control system (Fig. 4).

Hands (mechanical hands) are the other more common terminal devices. There are both voluntary opening hands and voluntary closing mechanical hands. They come in multiple sizes to best match the size of the contralateral hand according to metacarpal circumference or width. Prosthetic hands are worn with gloves, similar to the passive hands, which come in various shades. As with the passive hands, the gloves are not durable for children, get dirty/stained easily, and are difficult to clean. Although hands offer greater aesthetics, they tend to be less functional than hooks and are heavier in weight. Their friction is internal and only a prosthetist can adjust it so they have limited pinch force. In addition, the glove can restrict the motion making it more difficult to open and close especially for younger users. The most obvious limitation is the fingers (primarily digits 4 and 5) tend to "get in the way of the user" preventing picking up of smaller and flatter objects with compared to the hook. Younger children have greater difficulty controlling a hand as compared to a hook (Fig. 5).

Hook Versus Hand

The decision to go with a hook or a hand is unique to every patient. As noted above there are pros and cons to both. Typically parents of younger children feel strongly about getting a "hand." Adolescents and older users frequently request a mechanical hand for aesthetic reasons. It is important for the team to discuss these issues with the user and family so that a decision can be made to meet both their expectations and functional goals. The decision in choosing a hook or hand can very well contribute to prosthetic abandonment whether it be for lack of appearance or secondary to lack of function. Encouragement of trying both terminal devices along with receiving therapy is recommended. The option of having a hook and a hand, especially for older children and adolescences, is an option as well. The terminal devices are relatively easy to change, and most users and families can learn to do this easily.

Child Amputee Prosthetics Project(CAPP) terminal device is a voluntary opening terminal device designed and developed by Carl Sumida, CPO, at UCLA in the mid-1970s. The CAPP terminal device is neither a hook nor a hand. It is made of rubber and has a center-pull to activate opening and closing of the terminal device. The benefit of the CAPP terminal device is that it provides secure grip and excellent pinch (Shaperman 1975). Appearance of the CAPP is sometimes an

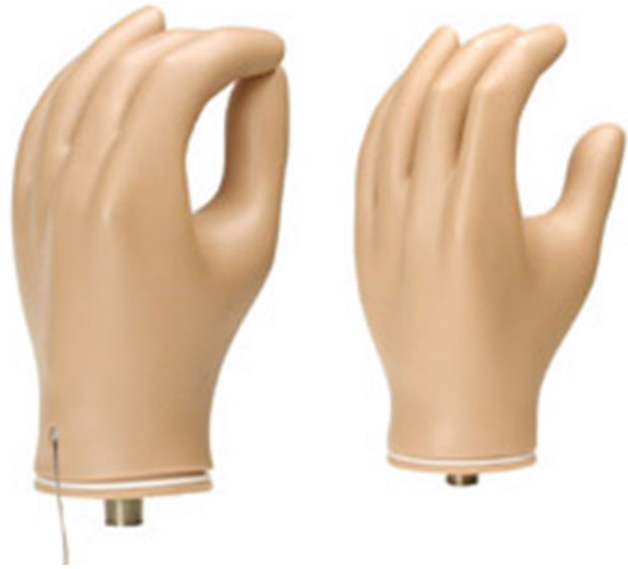

Fig. 5 Hosmer voluntary opening and voluntary closing hand

Fig. 6 CAPP terminal device

issue for the user and family. While it may be more functional than a mechanical hand, it is sometimes not well accepted by users and families (Fig. 6).

Life-touch terminal device is voluntary closing and was introduced in the late 1990s. It has more of the anthropomorphic detail of the hand (with 5 digits), but the fourth and fifth digits are flexed to minimize the issues of the hand's digits getting in the way when picking up smaller and flatter objects. It is a common terminal device for younger children as it is very functional especially for fine motor tasks. It is limited in grip force as it is voluntary closing. As noted above a locking mechanism can be utilized on the socket for activities requiring prolonged grip (Fig. 7).

Wrist Units Wrist units are laminated into the distal end of the forearm of the prosthesis. As noted above the wrist unit provides the connection between the terminal device and the prosthesis. In addition it provides passive supination and pronation of the terminal device and friction in the wrist to maintain the terminal device in desired position.

Friction wrist is the most common wrist unit. It is most often round and comes in various sizes: infant, child, medium, and large. The oval-shaped wrist unit is used only for wrist disarticulation deficiencies. The friction on the wrist unit is adjusted with a small Allen wrench that goes into an Allen screw on the side of the wrist unit. Turning the Allen wrench in the clockwise direction increases the friction (inhibiting rotation of the terminal device) and counterclockwise to decrease the friction (allowing easier rotation of the terminal device). Adjusting the friction is

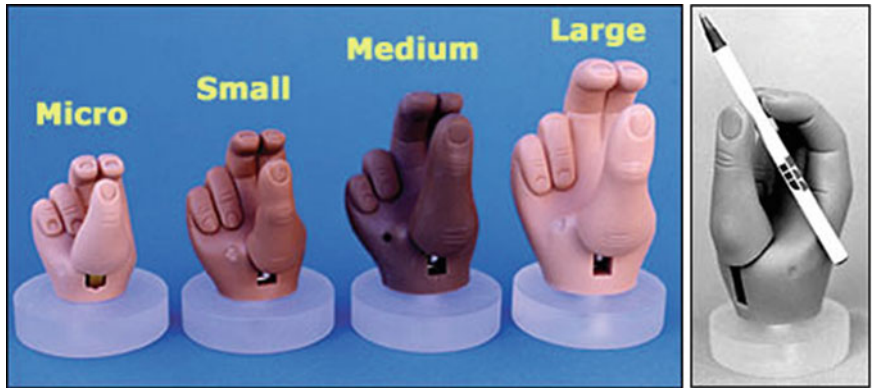

Fig. 7 TRS voluntary closing lite touch hand. TRS Catalog. http://www.trsprosthetics.com/catalog-view

Fig. 8 Hosmer friction wrist

easily done by the user (younger children will need assistance) only when needed depending on the functional need for the desired task (Fig. 8).

Flexion wrist while providing for friction also allows for three locking positions of the wrist: neutral (zero degrees), 30°, and 5° of flexion. It is predominantly used with bilateral deficiencies on the dominant side to assist with activities of daily living such as dressing, eating, toileting, etc. Flexion of the wrist allows the terminal device to get closer to the body without requiring shoulder internal rotation. It can also be helpful for some recreational activities that require wrist flexion like violin and guitar. The flexion wrist unit is heavier than the friction wrist, so it is typically not recommended unless there is sufficient need for functional use (Fig. 9).

Quick disconnect wrist allows for rapid change of terminal devices. The user pushes a button (or presses the button against an object) to release one terminal device and then replaces and secures another in its place. This is a much easier and faster process than screwing and unscrewing the terminal device each time a change is needed. This is especially useful if the user has a hook and a hand or when they have activity-specific terminal devices. It is not needed for infrequent need to change terminal devices (Fig. 10).

Flexible hinges are commonly used in the medium and long transradial prostheses and elbow disarticulation prostheses. In those instances the socket is much lower on the residual limb, allowing for greater range of motion (elbow flexion, supination, and pronation) and comfort. The flexible hinges assist with suspension of the prosthesis. The hinges are made of Dacron or leather and are attached proximally to a triceps pad (which is attached to the harness) and distally to the midline of the forearm of the prosthesis. Their purpose and function is to assist with suspension and stabilization of the prosthesis during active forearm supination and pronation (Fig. 11).

Elbow Joint Transhumeral and shoulder disarticulation prosthesis requires an elbow unit to provide elbow flexion and extension in order for the terminal device to grasp, hold, and release an object in the desired elbow position. The elbow is activated and controlled with the cable and harness along with shoulder and scapular motion. The prosthetic elbow must be positioned prior to activating the terminal device. Scapular and

Fig. 9 Hosmer wrist flexion unit

Fig. 10 Hosmer quick disconnect wrist

Fig. 11 Flexible hinges

biscapular motion will flex the elbow to the desired or required position. The elbow is then locked into position at which time scapular and biscapular motion will open or close the terminal device (depending if it is voluntary opening or voluntary closing) to pick up the object and complete the task.

A pre-flexed elbow is used with very young children (less than a year old). There are currently no prosthetic elbow units small enough nor is there a functional or developmental need for bimanual tasks. The goal of the prosthesis at this age is to assist with sitting balance, crawling, and getting the user accustomed to wearing a prosthesis. This design simply creates a longer socket originating proximally at the shoulder and extending down to the wrist unit and terminal device. The socket is flexed approximately 30–40° to assist with crawling and sitting.

A Passive friction elbow is a lightweight friction elbow which also allows for passive humeral rotation. It is not connected to the cable system or harness. It is passively positioned by the contralateral hand or an object such as a table, counter, or desk. It is used with young children who have the functional need for elbow flexion but do not yet have the developmental skills to utilize a cable-activated elbow unit. The friction is sufficient to position the elbow to activate the terminal device but is not sufficient for holding and lifting heavy objects. It offers greater function over the pre-flexed elbow and is the precursor to a locking elbow (Fig. 12).

Locking elbows allow the prosthesis to flex and lock into position. At rest the prosthesis is not locked. The elbow can "free swing" in walking and running as does the anatomic elbow. As described the cable that controls the elbow is connected to the harness. Tension to the cable flexes the elbow, and it is then locked into position with shoulder depression, abduction, and extension (all at the same time). The terminal device is then able to open or close (depending on whether it is voluntary opening or voluntary closing) as described above. When the task is complete or the elbow position needs to be changed, the same shoulder motions are performed to unlock the elbow. If a new position is required, the process will need to be repeated. Outside locking hinges are used with elbow disarticulation deficiencies. They come in three sizes (child, medium, and adult) and allow for seven different locking positions. Inside locking elbows are used with transhumeral and shoulder disarticulation prostheses. Inside locking elbow units allow for 11 different locking positions and also allow for passive internal and external rotation (substituting for humeral rotation) of the forearm via the turntable. This friction-controlled rotation easily allows the user to passively position the forearm using either the contralateral hand or an object. The friction is constant and does not often need to be adjusted. But when necessary it can be adjusted easily with an Allen wrench. Younger pediatric users sometimes have difficulty locking and unlocking the elbow even with training and practice. One option typically used especially with the unilateral user is to manually control the lock with a "pull strap" fabricated with Dacron. The user will flex the elbow to the desired position, then use their contralateral hand to pull the Dacron loop to lock the elbow so that the terminal device can be activated, and then manually pull the loop again to unlock the elbow. This is typically done for a limited period of time, during initial training, and used only until the user progresses and masters to the more conventional method as described above (Fig. 13).

Fig. 12 LTI friction elbow

Fig. 13 Hosmer locking elbow

A forearm lift assist is an adjustable spring that can be added to the locking elbow when the user cannot produce sufficient tension to flex the elbow throughout the full and desired elbow range of motion. It makes it much easier to achieve full elbow flexion. This is particularly important when trying to get the terminal device close to the face or mouth for feeding, shaving, or to assist with dressing and hair grooming. While adding a little more weight, it can be very helpful in optimizing function with the elbow and the prosthesis.

Shoulder Joint The shoulder is not a joint easy to replace mechanically. Prosthetic options for a shoulder disarticulation or forequarter prosthesis are limited. They offer the ability to passively position the shoulder in flexion, extension, abduction, and adduction with constant (but adjustable) friction. The joint can be locked into position using a cable or switch when needed (Fig. 14).

Socket design: All upper extremity prosthetic sockets are made from a model of the residual limb. The total contact socket is fabricated from thermoplastic or laminated material. It is the foundation for the entire prosthesis. While not weight bearing a well-fitting socket is still required for comfort as well as to optimize the functional outcome of the components, elbow and terminal

Fig. 14 Hosmer shoulder

device. A less than satisfactory socket has a direct effect on the efficiency of the cable and harness and will result in less than optimal function, which may result in the user not wearing, rejecting, or abandoning the prosthesis.

Wrist disarticulation and transradial sockets vary in design depending on the length of the residual limb. The longer the residual limb, the more distal the socket trimlines, and the more active pronation and supination are permitted. Typically for mid to long residual limbs, the socket is below the humeral epicondyles but contains the olecranon. Residual limbs shorter than 50 % of the forearm length require more proximal trimlines. This socket typically includes the humeral epicondyles, olecranon, and extends anteriorly to or just distal to the cubital fold. This trimline can limit the elbow flexion range of motion beyond 100°, which can limit the ability of the user to get the terminal device to their mouth, but aids in suspension of the prosthesis. This socket design is sometimes referred to as a "self-suspending or Muenster socket."

Elbow disarticulation sockets include the humeral epicondyles and can be bulbous in shape.

This can tend to result in a larger bulkier socket. In addition the elbow unit must be placed beneath the socket, and this results in the mechanical elbow being distal to anatomic elbow on the contralateral side. Aesthetically this can be an issue, but users tend to have good control of the elbow and terminal device as compared to higher level upper limb deficiencies.

Transhumeral sockets vary in design according to the length and shape of the residual limb. Similar to the transradial socket, the trimlines are determined by the length of the residual limb. The shorter the residual limb, the more proximal the trimlines need to be extended over the acromion, the scapula, and the pectoral muscles. The socket must fit adequately to control rotation and migration of the socket. This is more of an issue in the transhumeral socket than the transradial or elbow disarticulation socket. An ill-fitting socket will limit and interfere with activation of the elbow and terminal device. A well-fit, controlled, and suspended prosthesis is much easier to operate and will assist with maximizing functional outcomes with the elbow and terminal device.

Shoulder disarticulation sockets are often a challenge in that they need to extend in all planes to maximize fit and comfort, minimize rotation and migration, and distribute the weight of the entire prosthesis over a greater surface area to avoid pressure and breakdown on the bony residual limb and acromion process. Flexible inner sockets fabricated with thermoplastics and silicones (for comfort) along with a more rigid frame (for stability) are a commonly preferred design.

Suspension

Locking/lanyard liner: Silicone or similar liners are commonly used in transradial and transhumeral prostheses. In most instances a prefabricated liner can be utilized. They come in many sizes, thicknesses, and material options. The liner is rolled directly onto the residual limb. Each locking liner has a locking "pin" on the distal end which engages into a lock which is laminated directly into the socket. The liner will remain "locked" into the socket until a button on the distal medial side of the socket is pressed at which time the pin disengages from the lock and the socket can be removed. The alternative to a locking pin liner is a lanyard, or strap, made of Dacron or leather that is attached to the socket either at or near the distal end of the liner. The strap then exits the socket through a small cutout in the medial wall of the socket. The Velcro strap attaches to the outside of the socket, typically on the medial wall of the socket. The Velcro strap is removed for doffing of the prosthesis. A major benefit of pin or lanyard lock is decreased dependence for suspension of the prosthesis on the harness. While the harness is still required and it will aid in suspension and control of rotation of the socket, with a locking liner the harness can be dedicated to maximizing operation of the terminal device and elbow. It is important to note that while this system is excellent for suspension of the prosthesis, neither the locking nor lanyard locking liners eliminate the issue of socket rotation and proximal "gapping." Adequate suspension along with optimal fit of the socket is required to maximize the usefulness and functional outcomes with the prosthesis (Fig. 15).

Harnesses The function of a harness is suspended (or assist with suspension) of the prosthesis and activation and control of the terminal device and/or elbow joint through the cable system. Proper fit of the harness is extremely important as it directly correlates to the ability to control and optimize prosthetic use by the user. Less than optimal harness can impair function which can be a factor in rejection and abandonment.

Transradial figure of 8 harness is the most common harness. An axillary loop wraps around the contralateral shoulder and attaches to a metal or plastic ring posteriorly inferior to C7 and toward the contralateral side. The anterior suspensor strap originates from the same metal ring, extends toward the side of the deficiency, goes over the shoulder anteriorly in the deltopectoral groove, and attaches to the triceps cuff. The posterior control strap originates on the ring and extends in a distal and lateral direction with a

Fig. 15 Ossur upper extremity liner and Icelock 700

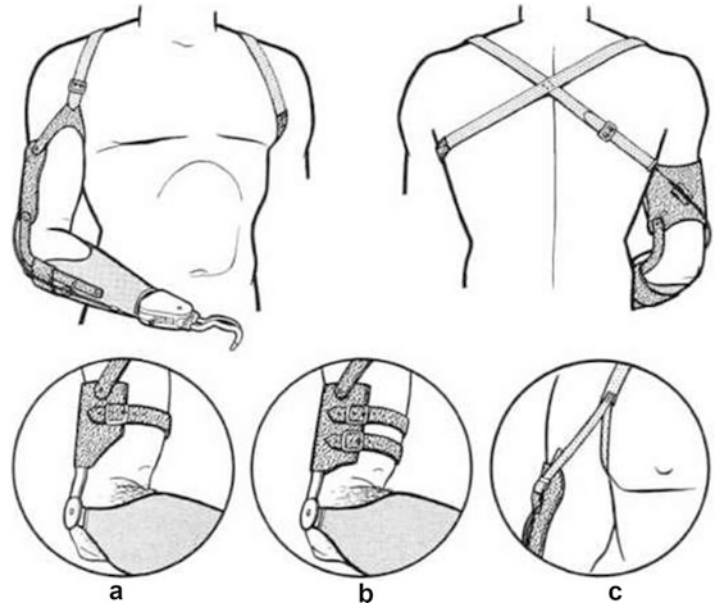

Fig. 16 Figure of 8 harness (RJ parsley harness patterns for upper extremity prostheses)

metal hanger at the end of the strap. The hanger is connected to a cable which is connected to the terminal device. The harness must be fit snugly. If not the prosthesis may not suspend adequately, or the terminal device may not operate properly (Fig. 16).

Transradial figure of 9 harness is commonly utilized with the short or very short residual limb and self-suspending (Muenster) socket (Northmore-Ball et al. 1980). The harness is similar to the figure of 8 except that there is no anterior suspensor strap. A figure of 9 harness is not as tight fitting or restricting as the figure of 8 harness because the harness is not required for prosthetic suspension (Fig. 17).

Transhumeral prostheses also utilize the figure of 8 design. The axillary loop, posterior ring, and posterior control straps are the same as in the transradial figure of 8 harness. The anterior suspensor strap is similar to the one in the transradial

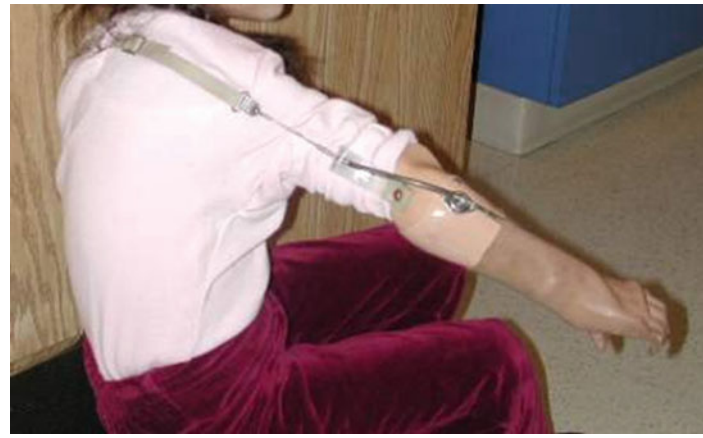

Fig. 17 Figure of 9 harness

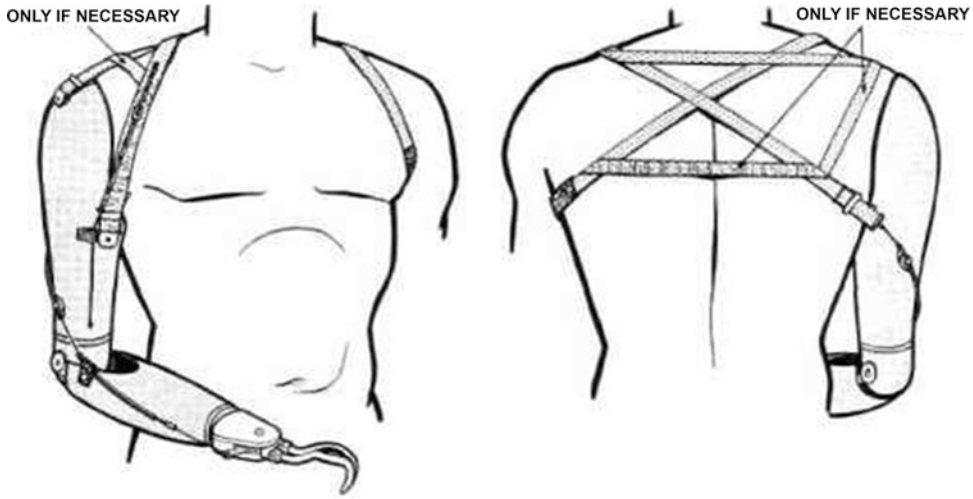

Fig. 18 RJ parsley harness patterns for upper extremity prostheses

harness, but instead of attaching to the triceps cuff, it distally connects to the elbow lock and has elastic webbing. There is an additional lateral suspensor strap that is sewn onto the anterior control strap and attaches to the socket proximally to assist with suspension and to control rotation and movement of the socket on the residual limb. Proper fit of the harness on the transhumeral prosthesis is even more critical than in the transradial harness as the shoulder motion has to control both the elbow and terminal device. A loose or poorly fitting harness will result in a poorly suspended prosthesis with limited and inconsistent performance of either or both the elbow and terminal device (Fig. 18).

Cable Activation of Transradial Prosthesis

The cable is metal or nylon and is attached distally to terminal device and proximally at the hanger on the control strap of the harness. It is covered by the cable housing which is mounted to the proximal lateral portion of the socket. Proper placement of the mount on the socket is important as it effects cable movement and can impede terminal device function. Shoulder flexion and/or scapular abduction opens or closes the terminal device, depending on whether it is a voluntary opening or voluntary closing terminal device. The amount

of open or close is directly related to the amount of shoulder flexion and/or scapular abduction and the cable and harness fit. Relaxation will return the terminal device to its original passive position. Length and position (line of pull) of the cable and fit of the harness are keys to success and control of prosthesis by the user. Small modifications and adjustments in the cable and/or harness can dramatically affect the functional outcome.

Cable Activation of Transhumeral Prosthesis

The transhumeral prosthesis has two different cables. One cable opens and/or closes the terminal device and also flexes the elbow, and another cable locks and unlocks the elbow unit. The cable that controls the terminal device and elbow flexion is attached distally to the terminal device and proximally on the hanger of the control strap of the harness. Shoulder flexion and biscapular abduction open or close the terminal device (as described above), but the same motion will also flex the elbow. A second cable originates on the elbow unit and attaches to the anterior suspensor strap. Shoulder depression, abduction, and extension will lock or unlock the elbow. The typical sequence of operation is that the elbow is flexed to the desired position, the elbow is locked, the terminal device is then opened or closed, and then the elbow is unlocked and either repositioned or relaxed in extension. Use of the prosthesis requires this sequencing be repeated for each task. As with the transradial prosthesis cable length, position (line of pull) and proper harnessing is required to optimize functional outcomes.

Ipsilateral scapular cutaneous anchor is a relatively new option for upper extremity prosthetic harnessing. It eliminates the need for the figure of 8 and figure of 9 harnesses. This is noteworthy as the harness, particularly the axillary loop, is the most often complained about component on the prosthesis. In many instances, it is one of the main reasons reported for rejection. In eliminating the harness the control cable for the transradial prosthesis is attached to a thin piece of plastic. The plastic has an adhesive which then adheres to the skin on the scapula (on the involved side). The position of the attachment of the plastic is critical to ensure optimal operation of the prosthesis and cable. The adhered plastic piece remains on the skin for several days before it needs to be replaced. The cable is disconnected from the plastic piece with doffing of the prosthesis (Latour 2011). Use of the ipsilateral scapular cutaneous anchor requires the socket to be a well-fit self-suspending socket as the harness will not be available to assist with suspension. It also requires education and competency of the wearer and/or family to ensure that the plastic that adheres to the skin is placed properly and in the correct position. The ipsilateral scapular cutaneous anchor is not an option for all wearers secondary to their need for additional suspension of the prosthesis. Some wearers have also experienced skin issues (rash, breakdown, irritation) secondary to the adhesive (Fig. 19).

Externally Powered Prostheses

Unlike the body-powered prosthesis, the upper extremity externally powered prosthesis does not utilize a cable to activate and operate the terminal device or elbow. Prosthetic activation and operation is controlled with myoelectric electrodes (surface EMG), switches (push or pull), or touch pads, which are all battery powered. The battery, either incorporated into the socket or mounted to the socket, must be recharged as needed. The frequency of recharging depends on the frequency and use of the prosthesis by the wearer and the voltage of the battery. Most wearers charge their prosthesis daily, overnight, although some high-end users may require charging midday. Myoelectric control is the first choice of external power especially for a transradial deficiency. The wearer must be able to demonstrate good isolation of the musculature for control and operation of the prosthesis. The "myo-test" will determine optimal sites of the electrodes on the residual limb as well as to confirm the ability to differentiate the muscle contractions required to control the prosthesis with sufficient strength to activate the electrodes that are incorporated into the socket, directly against the skin and over the muscle.

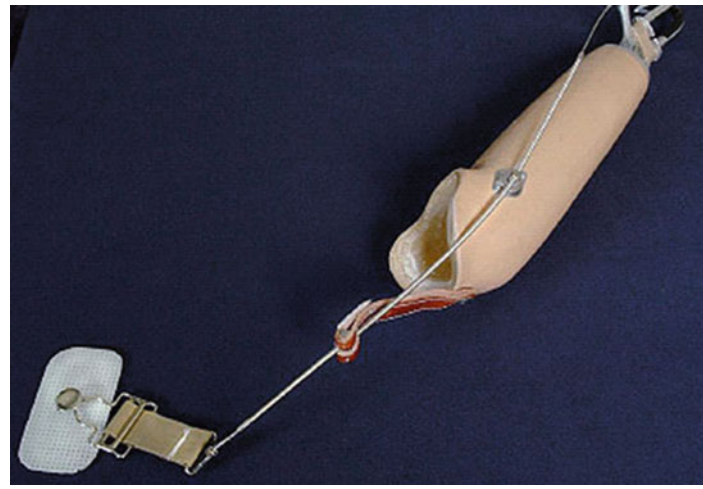

Fig. 19 Ipsilateral scapular cutaneous anchor

Switches and touch pads are utilized when there are no sufficient myo sites secondary to scarring or the inability of the user to activate the electrodes adequately in the myo-test. Switches are typically controlled through the harness with chest expansion, shoulder elevation/depression, scapular abduction/adduction, and when needed, with harnessing to a strap that attaches to a belt or belt loop. Touch pads are most often activated externally on the socket with the chin, sound side or internally through the socket if there are digits, nubbins, or any anatomy within the socket that has active motion that the user can volitionally control.

There are advantages and disadvantages of external power for the upper extremity prosthesis, especially for the pediatric population. Appearance is probably the most often reason for the request for an externally powered prosthesis as the terminal device of choice by most is a hand with cosmetic glove. Another reason is that the externally powered prosthesis does not have to require cables and harness (which wraps around the contralateral axilla) to operate the hand or elbow. This tends to allow more freedom, less bulk, improved comfort, and improved appearance. A harness is not needed for most transradial externally powered prostheses as the socket is typically self-suspending. The use of a suspension sleeve is sometimes desired for auxiliary suspension especially during heavy use. A harness is still required for the transhumeral and above user for suspension of the prosthesis. The harness is not a traditional figure of 8 in that it is solely being utilized for suspension. Frequently this can allow for different configurations that can maximize comfort and appearance. The biggest advantage of external power, over body power, is that proportional control of open and closes or elbow flexion is not dependent upon shoulder and scapular motion and strength. It is dependent upon activation of the power source whether it is by electrode, switch, or touch pad to operate the elbow and terminal device. Lastly, the grip force on an externally powered prosthesis is far greater than a body-powered terminal device. Training is of course required to master this control. The amount of training varies by the individual needs as well as the complexity of the design.

One of the major disadvantages of external power is that the prosthesis is considerably heavier than a body-powered prosthesis. The terminal device and elbow require a motor, a transmission, and a power source. The weight will vary by size of the components, but all are heavier than their body-powered counterparts. This is certainly a concern for the pediatric wearer and in some instances can be a cause of rejection. Socket fit is much more critical especially in the myoelectric prosthesis. The user must have and maintain excellent contact with the electrodes in order to be a successful user. This can become an issue for the pediatric wearer because as they grow their socket fit can become even slightly compromised

and they can lose contact with the electrodes and hence lose the ability to operate the prosthesis. While not disadvantages, lack of durability (particularly the glove that covers and protects the myo hand), need for repairs, and maintenance are concerns. Lack of proper maintenance, especially when it involves exposure to water and other extreme weather elements, can cause permanent damage to the prosthesis requiring repair, expense, and even replacement. Most importantly, while the myo hand offers greater appearance, like its mechanical counterpart, it does not replace the anatomical hand and is not as functional as a hook terminal device. There are myo hooks and tools available, but they do not come in pediatric sizes and are typically even heavier than the myo hand.

There are many successful pediatric myo wearers. Keys to success begin with the clinic team and include extensive discussions on myo use, pro, cons, and limitations with the child and family. Proper myo-testing is also imperative as it is the indicator for the ability to operate the prosthesis. Some clinics require past experience wearing a body-powered or passive prosthesis prior to recommending a myoelectric prosthesis. Their rational is that the wearer has already demonstrated some level of prosthetic wear and history which will hopefully limit the rate of rejection of the myoelectric prosthesis. Lastly working with prosthetists and therapists experienced with pediatric prosthetics and myoelectrics is imperative. Improper fit and training can easily lead to frustration, limitations in function, and rejection of the prosthesis.

The transradial external prosthesis is most often myoelectric and self-suspending, requiring no harness. Some users wear a neoprene suspension sleeve for high activity use. The wrist extensor muscles control opening of the terminal device, and the wrist flexor muscles control closing of the terminal device. Younger, preschool wearers can sometimes have difficulty differentiating and isolating wrist extensor and flexor muscle contraction and control. Some congenital transradial amputees or traumatic amputees with substantial scarring do not have two separate myo sites. In these instances modifications are made, and a single-site electrode is the design that is used. It is placed wherever the child can volitionally activate the electrode. Toddlers utilizing the single-site design will typically activate the electrode to open the terminal device, and relaxation will passively close the terminal device around the desired object. As the child gets older, transition to a two-site electrode system as described above is preferred. For wearers who cannot utilize a two-site electrode system, the terminal device can be programmed to perform both the open and close functions utilizing both quick and sustained single muscle contraction. A myoelectric wrist rotator can also be added to the myoelectric prostheses for adolescents and adults if there is sufficient room for the components. The rotation is controlled with the same wrist extensor and flexor muscle groups. Quick muscle contractions will activate and control rotation. Wrist rotators will add additional weight to the prosthesis (Fig. 20).

The transhumeral prosthesis, like the transradial, can also be externally powered and myoelectric. One of the major limitations is component size of the elbow. There is only one electric elbow commercially available for younger children (8–12 years old), and none are available to the preschool-aged children. Depending on the length of the residual limb and the design/fit of the socket and prosthesis, it may be self-suspending or may require a harness for suspension and rotational control. The biceps brachii muscle controls flexion of the elbow and closing of the terminal device. The triceps muscles control extension of the elbow and open the terminal device. As with the transradial prosthesis, a myoelectric wrist rotator can also be added for older children and adolescents. It is important to keep in mind that the more functions that a muscle group controls, the more difficult isolation of each function gets. Training, including use of biofeedback, and practice are typically required (Fig. 21).

Hybrid prostheses are a combination of body-powered and externally powered prostheses for the transhumeral and proximal deficiencies. In some instances the terminal device is body powered via the cable and harness, and the elbow is externally powered. In others the elbow

Fig. 20 Otto Bock transradial myoelectric prosthesis

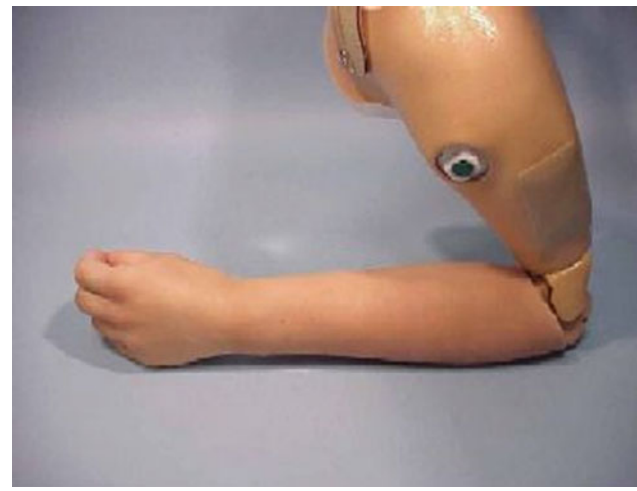

Fig. 21 LTI VASI 8–12 powered elbow

is body powered and the terminal device is externally powered. The decision on which component is body or externally powered is dependent upon the user's ability to activate and control as well as the weight and size of the components. Younger (adolescent) users may be best served with having externally powered elbow but a body-powered hand. In this instance the heavier elbow is controlled electronically, while the cable and harness can more easily activate and control the terminal device. But more often the wearer and family request a myoelectric hand and cable-activated elbow for aesthetic reasons.

In recent years new designs of externally powered hands have been introduced. The major difference from the more traditional design is that all of the digits have the ability to open and close, there is self-selection in what digits are activated, and there are multiple options on grip and grasp. While offering more options to the users, they are more mechanical and considerably more expensive than the more traditional options. Appearance is another limitation in size, color, and durability of cosmetic glove. Currently these hands are only available in adult sizes (Fig. 22).

Fig. 22 Touch Bionics i-limb ultra hand

Sports and Recreation

"Play is essential to development because it contributes to the cognitive, physical, social, and emotional well-being of children and youth" (Ginsburg 2007). This principle applies equally to children with an upper limb deficiency. "Through sports and recreation children with limb deficiencies can demonstrate competence and self-confidence that will transfer to other aspects of their lives" (Anderson 1998). It is important to keep in mind that in many instances an upper limb prosthesis is not a requirement or prerequisite for participation. Many learn to make their own "homemade" modifications and these adaptations work well. There are prosthetic components and designs that are specific to many sports and activities including terminal devices specific for musical instruments, photography, weight lifting, swimming, golf, etc. Almost all of them can easily be used with the users existing body-powered prosthesis. The threads on the adaptive device are the same as those on a conventional hook or hand. The terminal device can be removed from the wrist unit, and the adaptive device is screwed back into the wrist unit. The use of a quick disconnect wrist unit (as mentioned earlier) can make this process even easier and faster. Many of these terminal devices do not come in pediatric sizes, so children will have to wait until they are older to use them. Most limb deficiency clinics have an array of these devices to show to users and their families prior to recommending them. Some athletic participation at higher levels requires sports-specific prosthetic fabrication. Weight lifting, heavy game fishing, and impact sports require that the components (the wrist and socket and cable) be heavy duty to accommodate excessive weight and impact. Others may require water-resistant and or noncorrosive materials for swimming, water sports, and snow sports. It is important that the team works with an experienced prosthetist and in some cases a trainer, coach, and instructor to ensure that the design, materials, and terminal device meet the safety and activity-specific needs of the user. It is also important to keep in mind that children will frequently lose interest in a particular sport or activity quickly. In many instances the terminal device, like the other sports equipment, gets tossed to the back of the closet (Fig. 23).

Cost of these sport- and activity-specific devices is also an issue for many users and families. In many instances they are not covered under medical insurance as they are deemed "not medically necessary." Others may limit the number of activity-specific terminal devices they will cover. Working with the team appeals with supporting documentation may be useful. When that is not an option, local fund-raising or appealing to a charitable group can sometimes be helpful in assisting with part or all of the cost not covered.

Bilateral Considerations

There are unique challenges with bilateral upper limb deficiencies. Many feel strongly that they should be fit as early as possible as they do not have the option of having their sound or contralateral hand (Lehneis and Dickey 1992). Others feel the sensory loss once fit with prostheses far out

Fig. 23 TRS sports and recreation terminal devices

ways the advantages of having two terminal devices. Many children who were fit and trained with prostheses at an early age later rejected them secondary to lack of sensation, weight, and bulk. Others remain good wearers and users throughout their lives. Each child and family must be evaluated individually to determine what is "best for them." It is however important to keep in mind that the primary goal must be function and activities of daily living. Appearance concerns will take a "back seat" to function as a child can look fabulous in their prostheses, but if he or she cannot use them functionally, he or she will reject them. All children, regardless of whether they wear prostheses or not, should learn to do as many activities of daily living without their prostheses. This allows them to be as independent as possible without wearing their prostheses. This may include using their residual limbs for prehension, wearing a universal cuff, and learning to use lower extremities and feet for activities requiring greater dexterity. It is also important that children wearing prostheses be able to independently don and doff their prostheses.

Bilateral Body-Powered Prostheses

The components for the child with bilateral deficiencies are the same as for unilateral deficiency. There are some considerations that must be kept in mind when determining prosthetic design, components, and harnessing. Typically bilateral transradial sockets are fabricated with lower trimlines with flexible hinges. This is done to aid in ease of donning of doffing of the sockets. As noted above one wrist unit typically has the ability to flex to assist getting the terminal device closer to the body for feeding, toileting, dressing, and other self-care needs. One terminal device, if not both, is typically a conventional hook design to ensure ability for fine motor tasks and to pick up smaller and flatter objects. A forearm lift assist should also be considered for bilateral transhumeral deficiencies. Most bilateral prostheses are harnessed together, rather than two separate harnesses, in one continuous figure of 8 design.

Follow-Up Care and Growth Considerations

The transdisciplinary team's job does not end the day the child gets their prosthesis or completes their initial training. It is a relationship that continues throughout childhood and adolescence and continues through transition to an adult-based limb deficiency team. The children are seen at minimum every 6 months, or sooner for repairs, growth, and changes in medical necessity. The

discussion at each visit includes wearing patterns, concerns, issues, current sport and recreational activities, etc. Goals are reviewed and discussed to determine the plan of care and if and how a prosthesis will be a part of the plan. The frequency a new prosthesis is needed will vary and is not as exact as with a lower extremity prosthesis. Small increments in longitudinal growth do no necessitate a new prosthesis. A slightly shorter prosthetic arm, compared to the contralateral side, does not typically limit the function of the prosthesis nor is it as noticeable (cosmetically) during most activities. Circumferential growth can typically be accommodated with socket adjustments, up to a point. Ultimately the circumferential growth is the determining factor necessitating a new prosthesis. A poorly fitting prosthesis will not function properly and will frequently result in decreased wear and use unless adjusted or replaced.

Cost and Medical Coverage for an Upper Limb Prosthesis

The cost of upper limb prostheses, especially for external power, can be costly and become a financial burden for families. In the pediatric population growth, repairs, adjustments, and replacement of prostheses occur at a higher frequency than the adult population. It is important that families are knowledgeable regarding their own individual medical plan, including their deductibles and all coinsurances. In addition it is important that they be aware of the language in their coverage regarding replacements, allowable frequency for new devices, and any language that discussed exclusions in coverage for items such as "passive prostheses," "myoelectric prostheses," and "cosmetic restoration." The team, when requested, can assist with establishing medical necessity and with appeals when services are denied. But it is extremely important that these financial discussions occur with the team and the prosthetic provider in advance of delivery of the prosthesis.

Pediatric Upper Limb Prosthetic Outcome Measures

Outcome measurement of pediatric upper limb prosthetic wears is a topic discussed, debated, and studied. When looking at outcomes the biggest challenge is in defining success. Is the ability to wear a prosthesis for a certain period of time a success? Is the ability to open and close a terminal device on demand a success? Is the ability to perform specific skills and tasks a success? Or is having a good self-image and quality of life a success regardless of the ability to operate a prosthesis?

There are many tools that have been created over the years to assess pediatric upper limb prosthetic outcomes. Some are observational, others are self-reported questionnaires completed by parents, and others are completed by the child. Most are limited to unilateral congenital below-elbow deficiency. Generally, the Assessment of Capacity for Myoelectric Control (ACMC) (Hermansson et al. 2005; Lindner et al. 2009), Unilateral Below Elbow Test (UBET) (Bagley et al. 2006), and University of New Brunswick (UNB) Test (Sanderson and Scott 1985) assess performance of hand function (ACMC only addresses myoelectric prostheses); Child Amputee Prosthetics Project-Functional Status Inventory (CAPP-FSI) (Pruitt et al. 1996) and Prosthetic Upper Extremity Functional Index (PUFI) (Wright et al. 2001) address functional abilities; Pediatric Quality of Life Inventory (PedsQL) (Varni et al. 2001) assesses quality of life; and the Pediatric Outcomes Data Collection Instrument (PODCI) (Daltroy et al. 1998) assesses participation (Wright 1970–2009).

These, and other measures, are valuable. One of the primary issues is that insurance payers are always concerned with the cost to benefit of providing upper limb prostheses to children. But it is extremely important to keep in mind that overall success is determined using several of the measures and correlating them together. That data would more clearly show the child with

a limb deficiency and their ability to function (with or without a prosthesis), participate, and compete with their peers in school, sport, recreation, and life.

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